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VISCOSITY CHANGES IN MULTIGRADED MOTOR  
OILS DURING SERVICE

by



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A THESIS

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THE UNIVERSITY OF ALBERTA  
FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Viscosity Changes in Multigraded Motor Oils During Service" submitted by Wayne Evan Coates in partial fulfilment of the requirements for the degree of Master of Science.

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## ABSTRACT

The principal objective of this project was to investigate the viscosity changes occurring in a multigraded motor oil during service, and to determine the effects of load and speed on these changes. The study used two different motors in the laboratory along with data obtained from University Service Vehicles. Three makes of oil were compared, for SAE grades 5W-20, 5W-30 and 10W-30, while only one make of SAE 10W-40 and of SAE 30 were tested. Various tests on lead contamination, fuel dilution, insolubles, oxidation products, and base oil volatility were carried out to determine which of these factors had the greatest effect on reducing the amount of polymer breakdown observed in the runs. The following conclusions were drawn:

1. The effects of load on viscosity change were negligible.
2. The effects of speed on viscosity change were large.
3. Base oil volatility was the most important factor tending to mask the polymer degradation.
4. Different motors as well as the number of service miles on the motor, produced different viscosity trends for the same oil and speed.
5. Different makes of the same grade of oil produce very different viscosity changes under the same speed and motor conditions, with some of the oils dropping an SAE grade at 210 F, others increasing an SAE grade at 0 F.



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## ABBREVIATIONS AND SYMBOLS

Abbreviations

API	American Petroleum Institute
ASLE	American Society of Lubrication Engineers
ASTM	American Society for Testing and Materials
bhp	brake horsepower
C	degrees Centigrade
CCS	Cold Cranking Simulator
CLR	Cooperative Lubrication Research
cm	centimeters
CRC	Coordinating Research Council
cs	centistokes
F	degrees Fahrenheit
ft	foot
ft-lb	foot-pounds
gm	gram
hp	horsepower
hr	hours
IG	Imperial Gallon
in.	inch
lb	pound
min	minutes
mI	millilitre
mm	millimeter
mph	miles per hour
PRL	Petroleum Refining Laboratory
psi	pounds per square inch



rpm	revolutions per minute
rps	revolutions per second
RV	Reciprocating Viscometer
sec	seconds
SAE	Society of Automotive Engineers
SUS	Saybolt Universal Seconds
VI	Viscosity Index
VI <sub>e</sub>	Viscosity Index extension

### Mathematical Symbols

$\dot{\gamma}$	shear rate ( $\text{sec}^{-1}$ )
$\mu$	dynamic viscosity (poise)
$\tau$	shear stress ( $\text{dynes/cm}^2$ )

### Graphical Symbols

Figures 13 to 16 and 30

—————	maximum sampling run, unloaded
— — —	maximum sampling run, loaded
— . —	minimum sampling run, unloaded
— .. —	minimum sampling run, loaded

Figures 20 to 22 and 24 to 29

—————	Oil X
— — —	Oil Y
— . —	Oil Z

Figures 17, 18, and 31

—————	1500 rpm
— — —	3000 rpm





Figure 23

———— 12000 miles on motor at beginning of run

— — — no miles on motor at beginning of run

All Figures

—X— 292 Ford motor

—O— Flathead Ford motor



## 1. INTRODUCTION AND OBJECTIVES

Since their introduction onto the market in the early 1950's, multigraded oils\* have become more and more prevalent until today both the oil companies and the car manufacturers can do nothing but build up the qualities of these oils. The market has become flooded with such a vast assortment of classifications of oils, that it is little wonder that the general public has given up trying to find out which is a "good oil", but rather buy any recommended by their local garage operator.

The big question is, however, are these multigraded oils all that they are built up to be, or do they have some faults which should be more fully investigated. There is no doubt in anyone's mind, especially in the colder-wintered areas of our country, that an oil which can remain thin at low temperatures would be advantageous. Such an oil would reduce engine wear due to lubrication starvation at cold starting and would also increase the motor's ability to start due to the less viscous characteristics of the oil. If, on the other hand, the oil at high temperatures could remain viscous, such as an SAE 30 weight oil, this would also reduce engine wear and increase engine life. Thus the oil companies claim to have gained these two advantages with their multigraded oils.

New oils can and do meet both of these specifications, that is at 0 F and 210 F the viscosities conform to the SAE classification, but what happens to the oil after running in a motor? Is it still able to

\* In this thesis the term "multigraded oil(s)" refers to multigraded motor oil(s) only.



meet these specifications, or is one or both broken? Here was where the idea for this project originated, that being to run a motor for a period of time and then to measure the viscosity of the crankcase oil to see if a grade change did occur.

Objectives of this research project were:

1. Investigate the effects of speed in bringing about a viscosity change in a multigraded oil.
2. Investigate the effects of load in bringing about a viscosity change in a multigraded oil.
3. Compare various makes of multigraded oils, before and after use, determining if differences exist among them and what these could be due to.
4. Determine if a change in SAE grade occurs during service for multigraded oils.
5. Compare the results obtained using vehicles in service with those found in laboratory engines to see if a correspondence exists.



## 2. REVIEW OF LITERATURE

### 2.1 Advantages of Multigraded Oils

Motor oils and their characteristics have become an ever-increasingly complex problem since the introduction of the VI improved oils in the early 1930's and the introduction of multigraded oils on October 3, 1950 (47).

Since their introduction, much work has been done showing the many advantages of the multigraded oils. Their advantages can be classified into several areas, each having been studied rather extensively. One advantage listed is ease of cold-starting (2,7,47,52) due to a lower viscosity for the multigraded oil as compared to its respective straight-grade, as well as due to the fact that a temporary shear is brought about, thus reducing the viscosity. Fuel economy, as a second advantage, is probably due to two effects: 1) lower starting viscosity when the engine is cold, and 2) multigraded oils are subject to temporary viscosity loss in the bearing areas, resulting in lower viscosity and lower friction (2,26,47,52), hence less power requirement and less fuel consumption. Stucker (47) has shown that a reduction in viscosity from SAE 30 to SAE 10W has produced a 25 percent reduction in engine friction.

Two other advantages derived from multigraded oils can be classified under the same heading, that being cleanliness of the engine. Not only is the engine generally cleaner (2,17), but a lower octane number is required, especially under stop and start driving conditions, due to the fact that there is a lack of heavy residual oil stocks in such lubricants. Hence any oil that enters the combustion chamber is burned cleaner, thus leaving fewer carbon particles on the cylinder walls. The result is a





reduced tendency to knock, or a lower octane requirement (17,23,47,52).

The purpose of lubrication as defined by Gruse (13) is to maintain, between the surfaces one is concerned with, a layer of something which will keep them from rubbing together and injuring one another. Based on this definition the lubricating value of the multigraded oils is higher whether it be at high or at low temperatures, for a straight-grade oil will be either too "thin" at high temperatures or too "thick" at low temperatures to provide this layer. The advantage here is wear reduction at either starting or running temperatures, thus reducing maintenance costs (2,5,7,47), and increasing engine life. The last advantage of multigraded oils is their ability to reduce oil consumption (5,47,52) due to their higher operating viscosity when compared to a straight grade, for example an SAE 5W-30 rather than an SAE 5W or SAE 10W oil.

## 2.2 Disadvantages of Multigraded Oils

The main disadvantage occurring in multigraded oils is the problem of shear stability. When such an oil is subjected to a shear stress, as is found in an operating engine, the viscosity is decreased. This decrease is due to the degradation or mechanical breaking up of the long polymers commonly known as VI Improvers (14,47,53). A secondary disadvantage is the temporary viscosity loss found in multigraded oils, the effect being only transitory for when the shear rate is lowered the viscosity increases to a higher value (47). This temporary loss is brought about by the "lining up" of the polymer molecules in the direction of the shear, hence lessening their effect on viscosity (34).

## 2.3 Past Work on Shear Stability

The problem of viscosity breakdown has been studied to varying degrees by several people. In 1965, West and Selby (55) carried out a



series of runs in two 1962 six cylinder Ford engines. The engines were run at different speeds, with and without loads for seven and one-half hours, during which time a two-ounce sample of oil was removed at suitable intervals. Viscosities of these oils were then measured at 0 F using a forced ball viscometer and at 210 F using Cannon-Fenske glass viscometer tubes. For the SAE 10W-30 oils used, a lessening in viscosity at 210 F ranging from 8.0 to 20.4 percent was noted while at 0 F the loss ranged from 0.7 to 20.8 percent. In the case of the one SAE 5W-30 oil studied there was a 19.3 percent loss in viscosity at 210 F, but at 0 F a 2.6 percent increase in viscosity was observed. The effect of load on these viscosity changes was found to be negligible, whereas the effect of speed was of utmost importance. The faster the motor was run, the greater was the viscosity loss. In a single extended run consisting of 42 hours the viscosity was still falling but at a much smaller rate with the greatest amount of loss occurring during the first seven and one-half hours.

The reasons put forward by Selby and West as to the differences in viscosity breakdown rate occurring with different speeds were twofold; firstly, as engine speed increases, oil flow rate increases and hence a given volume of oil should be sheared more frequently; secondly, as speed increases, shearing rates in the critical zones of the engine, that is the bearings and cylinder walls, increases. The possibility of dilution and oxidation products masking the true viscosity loss brought about by degradation of the VI improver was ruled out by the use of Vapor Phase Chromatographic Analysis in the case of dilution, and Total Acid Number Analysis in the case of oxidation products. Finally, the authors listed the reasons for the considerably smaller viscosity loss at 0 F as compared to that at 210 F as being distillation of the more volatile components



of the engine oils, solubility of the VI improver, or change in the shear stress dependence of the polymer after degradation.

Vick and Goodson (53) carried on with similar work and stated that viscosity of used engine oil is a function of the quantities of fuel dilution, of oil-soluble products of oxidation, and of insoluble suspended material plus the breakdown of any polymers present. All of these are affected by the conditions under which the oil is used: that is the engine's size, make, and design; the operation regarding speed, temperature and loading; and length and type of service. Thus, due to the many variables involved, absolute prediction of the viscosity was impossible.

Vick and Goodson used thirteen passenger cars in suburban driving for their test. The results showed that with use, oils did lose viscosity, with the loss essentially leveled off after 4000 miles of driving. The authors did considerable testing to either rule out or adjust for the effects of fuel dilution, base stock oxidation and insoluble build-up to present the true oil viscosity as not being influenced by anything other than polymer degradation.

In 1966, Domier (8) ran a series of five oils in a 1953 Chevrolet engine, run at 2000 rpm with a 40 bhp load. The author found that for two SAE 5W-30 oils run, a loss of eight to nine SUS at 210 F was recorded at the end of only three hours of operation with a permanent viscosity loss of 12 to 14 SUS (or 30 percent) occurring after 16 hours. Thus an SAE 5W-30 oil becomes an SAE 5W-20 oil after only several hundred miles of driving. Fuel dilution for the tests was ruled out as a possible factor decreasing viscosity as it was less than two percent.

In 1966 Preuss et al (29) conducted a road test with four-ounce





samples being taken at 1000 and 2000 miles of driving. Several makes and sizes of motors were used and although all produced a viscosity loss, repeatability between various motors was poor thus agreeing with Vick and Goodson (53) as to the impossibility of predicting viscosity end values. The authors also noted that for a typical oil that approximately 300 miles of driving were required for the oil to shear from an SAE 30 to an SAE 20.

In 1968, Murphy and Bennet (24) studied the problem using locally driven cars. Seven commercially available oils were used ranging from SAE 5W-20 to SAE 30. All of the oils showed early reductions in viscosity with use, with most of the change occurring during the first 400 miles of operation, with the SAE 5W-30 and SAE 10W-30 oils showing viscosities in the SAE 20 classification after only 100 to 200 miles of service. In addition to this the magnitude of the viscosity loss for the multigraded oils depended on the new oil viscosity, that is the higher the viscosity, the greater the loss.

In the same year Johnson and Wright (16) did viscosity breakdown studies on an SAE 10W-40 oil. A motored engine run at 2000 rpm, with a crankcase temperature held at 190 F, as well as a laboratory fleet car were used for the tests. A high initial viscosity loss was found with the vehicle, with a leveling off of the viscosity between 1600 and 2000 miles. The motored engine had a more severe viscosity loss with the viscosities in both cases falling well into the SAE 30 classification, the car after about 100 miles and the motored engine after one and one-half hours. In addition the authors found this drop to be dependent on the base oil, type and amount of polymer, and the average severity of service.





DiPerna et al (7) states that with a wide variety of commercially available multigraded oils there is an immediate large loss in viscosity with equilibrium usually being reached in less than 1000 miles of high speed operation in automobiles. The main idea presented in the paper was the difference between the shear-stable and shear-unstable oils, the latter shearing in the case of the SAE 10W-40 oil to the SAE 30 classification, the former remaining an SAE 10W-40 throughout service. Thus with the latest technological advances it is now possible to produce a "true" SAE 10W-40 oil, that being one which maintains an SAE 10W-40 classification throughout its service life. Such an oil is then able to match the performance of SAE 20W-50 oils while also offering excellent low temperature cranking and starting ability.

In 1969, Courtney and Roscoe (5) found that running the same vehicle for 2000 miles produced great variability between oil makes for an SAE 10W-40 grade. Some reached an SAE 30 weight after 750 miles of driving while others never dropped into the SAE 30 classification; however in all cases the greatest viscosity loss occurred during the first 1000 miles of operation. Also noted was the fact that in four taxicabs equipped with "identical" new engines the viscosity breakdown curves varied greatly when the engines were new, but by the time 12,000 miles were on the engines the viscosity breakdown curves varied only slightly. The authors also found that the absolute severity level of polymer degradation was considerably lessened at higher mileages. When the motors were new the SAE 10W-40 oil was sheared down to an SAE 30 weight in all four cases after approximately 300 to 500 miles of driving, however on the third oil fill, begun at 12,000 miles, none of the curves crossed into the SAE 30 classification. Also run were a series of tests on highway cruising. In these the SAE 10W-40 did not cross into the



SAE 30 classification while the SAE 10W-30 oil dropped slightly into the SAE 20 classification only to regain the SAE 30 classification after 5000 miles. In addition, all of the curves cited in the paper had high initial viscosity losses, which changed into a viscosity increase above the lowest sheared value after about 2000 miles of driving.

#### 2.4 Machines to Simulate Shear

In all of the laboratory testing consisting of running a motor and withdrawing oil samples from the pan there was a great cost in time, labor and materials. In order to operate the equivalent of 2000 miles, a motor must be run in the lab at 2000 rpm for 50 hours; during which time a great quantity of gasoline would be consumed. Also the initial oil sample used must be large, hence efforts were made to produce a device that would simulate shear breakdown equal to running in a motor while reducing sample size and eliminating the effects of crankcase dilution, oxidation products, and insolubles (27).

As early as 1955 Lawson (19) collected the results of several devices that had been used to predict shear stability. These consisted of sonic oscillators, sharp edged orifices, diesel fuel injectors, a pressure release valve, a McIntyre gear pump, and magnetostrictive oscillators. All of the devices compared quite favorably with each other but no attempt was made to correlate the bench tests with actual field results.

In 1964 Vick and Goodson (53) selected the then-proposed ASTM sonic shear test (51) for their work. The authors found that the test could be used to compare different oils formulated with the same VI improver, but that a poor prediction resulted when oils formulated with different VI improvers were included. This difference was claimed to be due to



one of two causes: 1) the amount of sonic breakdown relative to mechanical breakdown varies with polymer composition, or 2) other mechanisms operating in the engine are not operating in the sonic test.

In 1968 Pearce (27) devised and tested a mechanical shearing test involving a power steering pump. In the test oil pressure and temperature were controlled along with pump speed. The results of the series of runs conducted showed that the test closely simulated the mechanical shearing that occurs in an engine and agreed with the fact that polymer breakdown increases as viscosity increases. In addition the test proved to be relatively insensitive to polymer type, and correlation with field work was very good, with results after a four hour test showing the average breakdown expected in field service. Also in 1969 Preuss et al (29) used a mechanical method to simulate field characteristics. This consisted of running a Labeco CLR Oil Test Engine for a period of 40 hours which was equivalent to 2000 miles of high speed driving. The authors found the speed of the engine to be the most critical operating factor, that is the higher the speed the greater the viscosity breakdown. The agreement with field tests was found to be excellent, when compared to the CLR engine being run at 1500 rpm with a sump temperature of 160 F. In addition, sonic shear tests were run and generally a poor correlation with field tests resulted, due to the fact that the type of polymer tended to greatly influence the amount of shear occurring.

Although some of the bench methods developed to test shear stability of motor oils either cut down on running time or on size of operating sample or both, none really simulated conditions in a motor. Curves produced by such devices are comparable to those found in an operating vehicle, but here not only is there polymer degradation, there are the effects of oxidation products, insolubles, crankcase dilution,





and evaporation of the light ends of the base oil. It is interesting to note that in the literature reviewed none of the authors mentioned this fact, much less had they done any work on separating out the effects of these factors from pure polymer degradation so that the bench technique would represent the true polymer degradation occurring in a motor rather than a combination of all the effects.

## 2.5 Viscosity Measurement

The viscosity measurement of oils was adopted by A.S.T.M. in 1958 and revised in 1966 (43) for temperatures of 100 F and 210 F using the calibrated glass capillary type viscometers employing a low shear technique. These techniques are based on the premise that motor oils are Newtonian fluids, their viscosities remaining constant regardless of the rate of shear. This usually applies at moderate and high temperatures but motor oils become non-Newtonian at temperatures below 32 F (12). Work was carried out by several people on the use of high shear viscometers to predict the actual viscosity of oils found in motors where conditions of high temperature and high rates of shear exist. Such devices used were the ASTM Pressure viscometer and the Kingsbury Tapered-Plug viscometer (12), PRL Single Pass Capillary viscometer (18) High Shear Rate Rotational viscometer (3) and the Coaxial-Cylinder viscometer (20).

The measurement at 0 F proved to be somewhat more difficult, especially when considering multigraded oils. In the late 1950's, due to a lack of meaningful data, SAE winter grades of motor oils were still determined by viscosities obtained by extrapolation on the ASTM Walther chart. This chart is fairly accurate for mineral oils but for polymer oils there can be large errors (9,14,32). The problem seemed to lie in just what viscosity the engine recognizes (47). Thus there began a series of





tests (9,15,31,32,33) in which a motor was cranked after being cooled to 0 F in a cold room. Viscosity of a known oil was then related to cranking speed, input torque, starter voltage or amperage, and a calibration curve was drawn up, thus making it possible to measure the viscosity of an oil as the motor sees it. All of these tests were revealing meaningful data, but in order to develop a sound classification system for motor oils it was found necessary to standardize the test procedure for the cold cranking measurement of viscosity.

In June 1961, SAE requested the CRC to initiate engine cranking studies at low temperatures. In March 1963 the work was completed and CRC Report 374 was issued (35) detailing the CRC L49 engine cranking test. Soon it was found that a bench test would be necessary to simulate the CRC values (54) as the use of a motor for testing the oils at 0 F was not only costly but very cumbersome, due to the fact that the sample size was large and a large cold room was necessary to run the tests in (22). Time was also a factor, as the motor had to be let stand in the cold room before testing could commence so as to ensure proper test temperature.

Up to 1965, the Ferranti-Shirley cone plate viscometer and the Forced Ball viscometer had emerged as the most successful for predicting low temperature cranking characteristics of engine oils (54). Vick et al (54) showed that there was fairly good correlation for the Haake Rotovisco cone plate viscometer, and the PRL, single-pass capillary viscometer but ruled out the Mason Torsion Crystal viscometer and the Texaco High Rate of Shear Rotational viscometer due to their complexity and limited availability. Following this others studied various devices such as the Cone Plate viscometer (21,35), the RV (21,22,45) and the



CCS (21), with all three proving to be adequate at 0F and the RV and CCS adequate at -20 F. The problem was finally settled by the establishment of ASTM Tentative Method (32) for motor oil viscosity at 0 F. Correlation of the CCS with the CRC L49 engine cranking test was found to be nearly one to one, with a small tendency for the CCS to measure the oils slightly more viscous than the L49 test.



### 3. DEFINITIONS AND UNITS

#### 3.1 Viscosity

Viscosity has been defined as a liquid's internal friction, that is the resistance offered to motion either of a foreign body through it or of it against a foreign body (13) and also as the measurement of the resistance of a liquid to flow (10,11). The question may then be asked as to how to apply a system of numbers to viscosity. The simplest and most general case is that of a layer of liquid between two plates, one stationary and one moving with a uniform velocity. Here, Newton's definition of viscosity applies; the force required to keep the plate moving varies directly as the velocity, the area and the viscosity of the liquid ( $\mu$ ), and inversely as the film thickness. Stated in equation form:

$$F = A \frac{dv}{dx} \cdot \text{constant } (\mu) \dots \dots \dots (1)$$

where  $F$  = the force acting,

$A$  = the surface area,

$v$  = the velocity, and

$x$  = the film thickness.

Equation (1) can be transposed to read:

$$\mu = \frac{F/A}{dv/dx} = \frac{\text{force or shear stress}}{\text{velocity gradient or shear rate}} = \frac{\tau}{j} \dots \dots \dots (2)$$

Georgi (11) thus describes shear rate as the ratio of the flow rate or velocity to the clearance between two parallel surfaces moving in opposite directions. The units of  $\mu$ , the dynamic or absolute viscosity, are:

$$\frac{\tau}{j} \frac{(\text{dynes/cm}^2)}{(\text{sec}^{-1})} \quad \text{or} \quad \frac{\text{dyne-sec}}{\text{cm}^2}$$



which, by definition, has been called a poise. Viscosity is ordinarily measured by timing the flow, under gravity head, of a fixed volume of liquid through a small capillary tube following the ASTM method (43). For such a system, volume rate of flow varies directly as the pressure difference on the liquid at the two ends of the capillary tube and the radius<sup>4</sup>, and inversely as the length of the tube and viscosity of the fluid:

$$\text{volume rate of flow} = \frac{\text{pressure} \cdot \text{radius}^4}{\text{length} \cdot \text{viscosity}} \dots \dots \dots (3)$$

Thus for a fixed volume of liquid:

$$\frac{\text{volume}}{\text{time}} = \frac{V}{t} = \frac{P \cdot \pi r^4}{8 \cdot \ell \cdot \mu} \dots \dots \dots (4)$$

where  $p$  = pressure,

$r$  = radius,

$\ell$  = length of the capillary and

8 is an empirical constant from Poiseuille's law.

If flow is under the influence of gravity only,  $p = dgh$ , where  $d$  is density,  $g$  is acceleration of gravity, and  $h$  is the head. Thus, (4) becomes

$$\frac{V}{t} = \frac{\pi dghr^4}{8\ell\mu} \dots \dots \dots (5)$$

Solving for  $t$ , results in:

$$t = \frac{8V\ell}{ghr^4} \cdot \frac{\mu}{d} \dots \dots \dots (6)$$

From equation (6) can be seen that all of the factors for a properly designed instrument can be kept constant except  $t$ ,  $\mu$ , and  $d$ . Thus the measurement of time for oil running through such a device would give a result in terms of absolute viscosity divided by density. This  $\mu/d$  value has hence been given the name kinematic viscosity and is measured in stokes and centistokes.





### 3.2 American Petroleum Institute Gravity

The specific gravity of an oil is the ratio of the weight of a given volume of oil to the weight of an equal volume of water, both being at 60 F and both weights being corrected for the buoyant effect of air (11). The API Gravity scale is an arbitrary one which is related to specific gravity in accordance with the formula:

$$\text{degrees API} = \frac{141.5}{\text{Sp. Gr. } 60^{\circ}/60^{\circ}\text{F}} - 131.5 \dots \dots \dots (7)$$

Gravities are generally useful for indicating the general type and degree of refining of oils (11). In practice measurement is made by use of a hydrometer in accordance with the proper ASTM technique (38). The observed gravity is then reduced to that at 60 F by the use of ASTM tables (30), with the results being API gravity in degrees.

### 3.3 Flash Point

This is the temperature in degrees Fahrenheit of the oil, upon being heated, when a flash first appears on the surface as a small test flame is passed over it. This is conducted according to the correct ASTM method (41).

### 3.4 Pour Point

This is the temperature, in degrees Fahrenheit, five degrees above which no oil flow is observed when the container is held in a horizontal position for five seconds. The test procedure is given by ASTM (42).

### 3.5 Viscosity Index and Viscosity Index Extension

This is the ASTM method (37) of assigning numbers to indicate the extent to which the viscosity of a particular oil is dependent on temperature. The higher the  $VI_{(e)}$  the flatter is the viscosity temperature curve and the lesser is the viscosity of the oil dependent



on temperature. Originally, VI values ranged from zero to 100 and were calculated using the kinematic viscosities at 100 F and 210 F according to ASTM method (36). The calculation was:

$$VI = \frac{L - U}{L - H} = \frac{L - U}{D} \dots \dots \dots (8)$$

where L = viscosity at 100 F of an oil of zero VI, having the same viscosity at 210 F as the oil whose VI is to be calculated;

U = the viscosity at 100 F of the oil whose VI is to be calculated; and

H = the viscosity at 100 F of an oil of 100 VI, being the same viscosity at 210 F as the oil whose VI is to be calculated.

To get the values for L and H, ASTM tables (1) are consulted. This method works well for VI less than 100, but with VI greater than this the values are poor (28). Thus the ASTM adopted a new method (45) to compensate for this effect. By this method,  $VI_e$  above 100 are calculated in two steps as follows:

$$1) \quad N = (\log H - \log U) / \log KV_{210} \dots \dots \dots (9)$$

where  $H = L - D$ ;

L, D, and U are as described previously, and

$KV_{210}$  = kinematic viscosity of unknown oil at 210 F

$$2) \quad VI_e = \frac{(\text{antilog } N - 1)}{0.0075} + 100 \dots \dots \dots (10)$$

where 0.0075 and 100 are empirical constants.

### 3.6 Crankcase Contaminants

#### 3.6.1 Oxidation Products

These are new compounds produced by the reaction of



hydrocarbon oils with oxygen under heated conditions. These consist of larger molecules, which tend to increase the viscosity of the lubricating oil, and acidic compounds, which are detrimental to the engine from a corrosive standpoint. The reaction can be greatly accelerated by certain metals found in a motor, such as iron, copper, and lead, which act as oxidation catalysts. Similarly, combustion chamber blow-by solids, air-borne dust, and temperature can catalyze the reaction. Georgi (11) has stated that for each 20 Fahrenheit degree rise in temperature, oxidation doubles, for the range of temperatures developed in an operating engine.

### 3.6.2 Insolubles

Insolubles include contaminants which get into the oil from external sources, such as dust, dirt, metal particles, and combustion chamber blow-by products (lead salts, soot, carbon and fuel resins from the thermal decomposition and oxidation of fuel "heavy ends"). These are often referred to as the "extrinsic insolubles" whereas the "intrinsic insolubles" are the "resins" formed by the oxidation of the oil itself (11).

### 3.6.3 Crankcase Dilution

Dilution, as determined by ASTM method (39), is the percentage of gasoline found in a used oil sample. This is most likely to occur during cold weather, in low-temperature operation which involves much idling, or where thermostatic control of coolant temperature has failed. Dilution can also occur when the boiling range of the fuel is too high, such that vaporization is not complete, or through leaks in the fuel pump diaphragm.



#### 3.6.4 Water Contamination

This is the percentage of water present in used crankcase oil as determined by ASTM method (44). Water contamination is brought about by leaks in the cooling system, by natural breathing and condensation, or by the end products of combustion, as one gallon of fuel produces approximately one gallon of water upon combustion.





#### 4. SHEAR RATE AND SHEAR STRESS

##### 4.1 Motor Values

The viscosity drop occurring in a multigraded oil during service is due to the shear stress applied by the motor. Shear stress varies directly as the shear rate produced by the motor and the viscosity of the lubrication. Thus for a motor run with two different oils at the same speed, the higher shear stress will occur with the higher viscosity oil sample, as the shear rate is constant. This is the reason Murphy et al (24) and Pearce (27) found that the greatest viscosity loss occurred with the oils initially having the highest viscosity.

Georgi (12) calculated the various values of shear rate found in a typical motor for the pistons and cylinders as well as for the crankshaft bearings. The shear rate is inversely dependent on the clearance between the moving parts under consideration, and for clearance values Georgi chose 0.01 in., 0.001 in., and 0.0001 in. For the motors run in the experimental work for this thesis these same three values were again assumed. Of the two motors used (described in section 5.1.1), the flathead Ford had a stroke of 3.75 in. while the 292 Ford had a stroke of 3.30 in. (49). These values result in speed or velocity values for the piston of 375 in./sec for the flathead Ford and 330 in./sec for the 292 Ford when run at 3000 rpm. For running at 1500 rpm these values are halved. Following is a table of the shear rates probably occurring in the motors used for the 3000 rpm speed.



TABLE I: SHEAR RATES FOUND ALONG PISTON (3000 rpm)

Velocity of Piston	Clearance Between Piston and Cylinder	Rate of Shear
375 in./sec	0.01 in.	$37,500 \text{ sec}^{-1}$
	0.001 in.	$375,000 \text{ sec}^{-1}$
	0.0001 in.	$3,750,000 \text{ sec}^{-1}$
330 in./sec	0.01 in.	$33,000 \text{ sec}^{-1}$
	0.001 in.	$330,000 \text{ sec}^{-1}$
	0.0001 in.	$3,300,000 \text{ sec}^{-1}$

The crankshaft bearings produce a rate of shear dependent on the speed, the clearance, and bearing diameter. Assuming a two-inch diameter bearing, the calculation for shear would be as follows:

$$3000 \text{ rpm} = 50 \text{ rps}$$

$$\text{velocity of surfaces} = 2\pi r \cdot \text{rps} \dots \dots \dots (11)$$

$$= 2\pi(1) \cdot 50$$

$$= 314 \text{ in./sec}$$

At 1500 rpm, velocity would be 157 in.sec.

The approximate shear rates found in the crankshaft bearings at 1500 and 3000 rpm are tabulated on the following page for the motors used in this thesis.



TABLE 2: SHEAR RATES FOUND IN CRANKSHAFT BEARINGS

Velocity	Bearing Clearance	Rate of Shear
314 in./sec	0.01 in.	31,400 sec <sup>-1</sup>
	0.001 in.	314,000 sec <sup>-1</sup>
	0.0001 in.	3,140,000 sec <sup>-1</sup>
157 in./sec	0.01 in.	15,700 sec <sup>-1</sup>
	0.001 in.	157,000 sec <sup>-1</sup>
	0.0001 in.	1,570,000 sec <sup>-1</sup>

From these shear rate values the shear stress can be calculated for each of the oils. The flathead Ford applies a more severe condition to the oils, due to its higher shear rate produced by the greater length of stroke and hence a faster piston speed for the same rpm.

#### 4.2 Cold Cranking Simulator Values

Tao and Appeldoorn (48) calculated the values of shear rates and shear stresses found in the CCS for the range of calibration oils used. Shear rate values varied from 62,000 sec<sup>-1</sup> to 9000 sec<sup>-1</sup>, while shear stresses remained fairly constant at 700,000 dynes/cm<sup>2</sup> for oils in the region of 10 to 80 poise. The shear rates were derived from the formula:

$$j = \frac{\left(\frac{N}{60}\right) 2\pi R}{h} \dots \dots \dots (12)$$

where N = rotor speed in rpm,

R = radius of rotor = 0.375 in.

h = clearance between rotor and stator = 0.00035 in.

which is the velocity difference of the moving surfaces divided by the clearance between them, that being the basic definition of shear rate as given by Georgi (11).



## 5. EXPERIMENTAL PROCEDURE

The experimental tests were conducted at the University of Alberta, at Edmonton, Alberta, in the Department of Agricultural Engineering laboratories.

### 5.1 Equipment

#### 5.1.1 Motors

Two motors were used for the series of runs. The first motor employed was a 1949 flathead (L-head) V8 Ford, hereafter referred to as flathead Ford (figure 1). This was the 8BA model, having a displacement of 239.4 in.<sup>3</sup> and a compression ratio of 6.80:1. The specifications list the motor as having 100 bhp at 3600 rpm and 180 ft-lb of torque at 2000 rpm (49). The second motor used was a 292 in.<sup>3</sup> Ford V8 (figure 2), hereafter referred to as 292 Ford. The exact year of the motor was not known, but production of these motors was begun in 1955 and ended in 1962. During this period of manufacture the motors had between an 8.1:1 and an 8.8:1 compression ratio. The specifications of the motor also varied, with the bhp values ranging from 193 at 4400 rpm to 170 at 4200 rpm, while the torque values varied from 280 ft-lb at 2600 rpm to 279 ft-lb at 2200 rpm (49). The 292 Ford was completely rebuilt and had not been run previous to the author's use, whereas the flathead Ford had been run, the length of time not exactly known but in the neighborhood of 20,000 miles. The oil filter in the flathead Ford was by-passed using a piece of copper tubing. In the case of the 292 Ford, the filter could not easily be by-passed, thus the engine was operated with the filter in place, but less the cartridge.





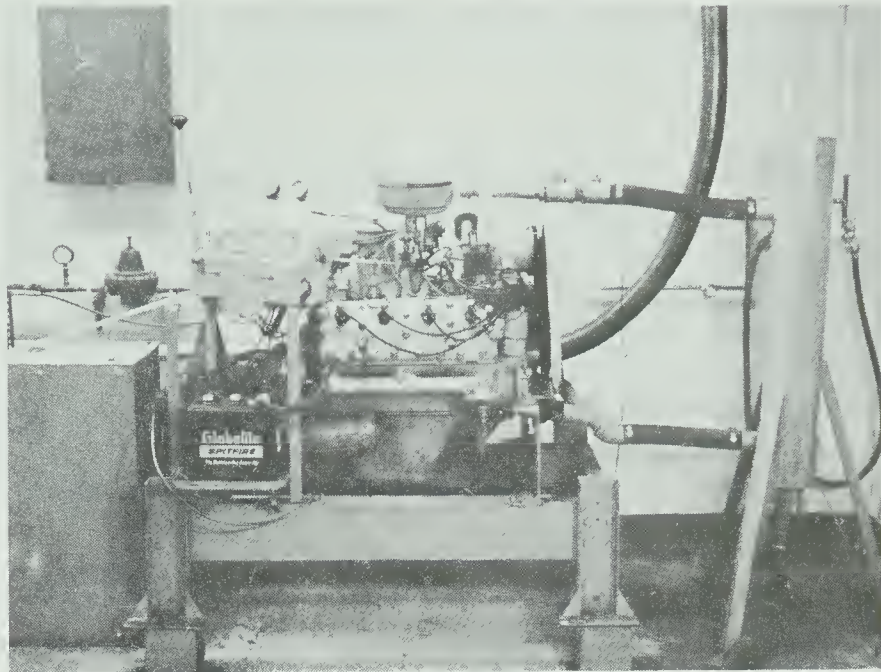


Figure 1: Flathead Ford motor.

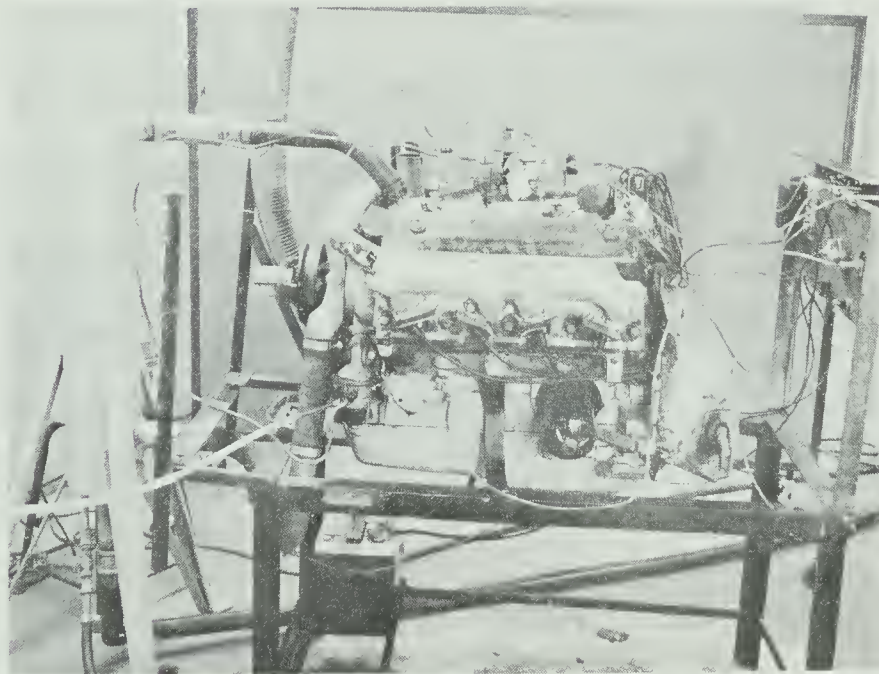


Figure 2: 292 Ford motor.



### 5.1.2 Safety Gauges

In each motor, two safety devices were mounted to protect the motor in the event of coolant failure, or loss of oil. The safety switches were produced by the Murphy Safety Switch Company of Tulsa, Oklahoma.

The operation of these was brought about by the temperature of the outlet water rising too high (200 F), or the oil pressure falling too low ( 30 psi). This caused the needle arm (A in figure 3) of the appropriate gauge to make contact with an adjustable screw (B in figure 3), thereby shorting out the coil and causing the motor to stop.

### 5.1.3 Cooling Columns

On each motor, the fan and radiator were removed and cooling was accomplished by the aid of a cooling column (figure 4). These were connected to the motors in such a way that inlet water to the motor was brought in from the bottom of the column, while outlet water was expelled at the top of the column, the propelling force being the normal water pump used in the motor. In addition, the cooling column had an inlet for cold tap water at the bottom and an outlet at the top of the column to expel the extra water and maintain a constant head.

### 5.1.4. Temperature Measurement

A Honeywell recorder made by Brown Instruments Division of Philadelphia, Pennsylvania was used for temperature measurement in conjunction with a potentiometer (figure 5) and two copper-constantan thermocouples (figure 6).

### 5.1.5 Gasoline Containers

Fuel for the motors was supplied from a 25 gallon drum via a copper tube inserted into the small bunghole in the barrel, and a



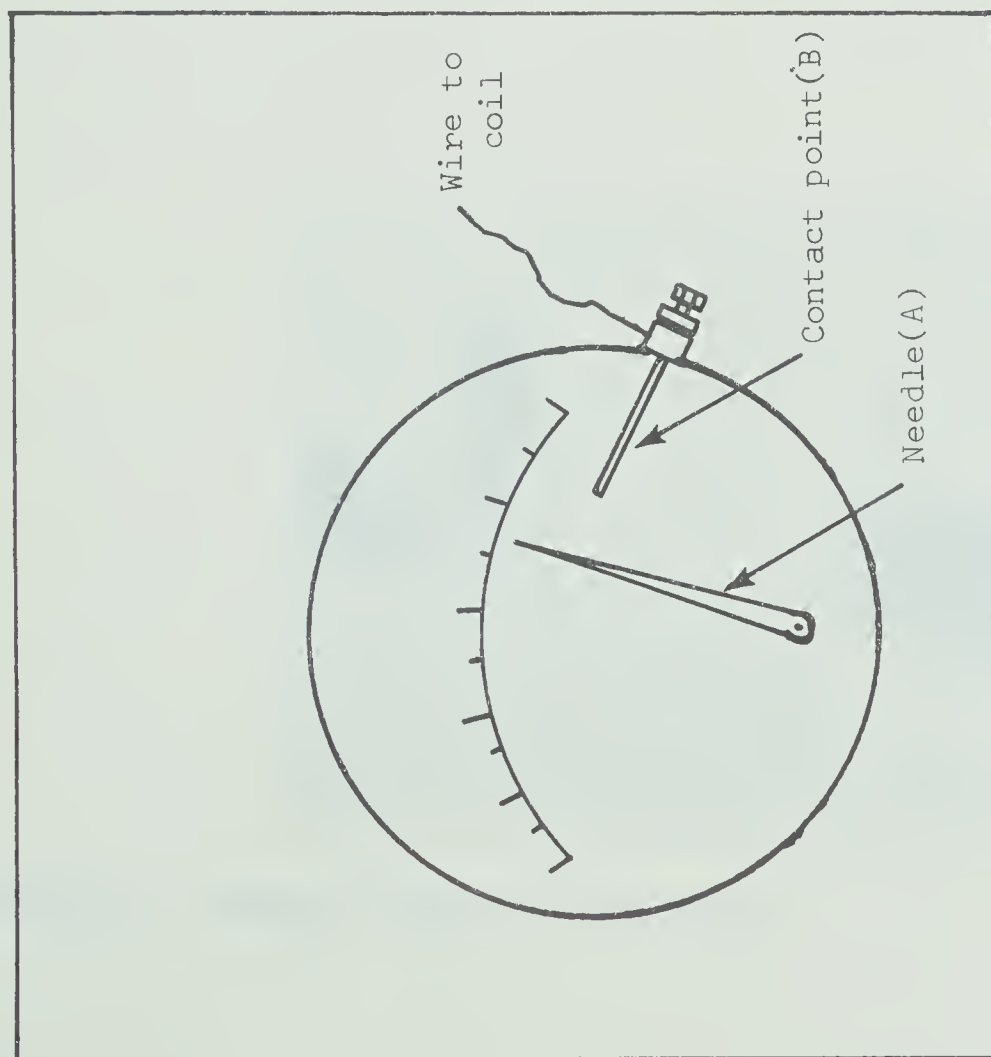


Figure 3: Schematic diagram showing safety gauge in operating position.

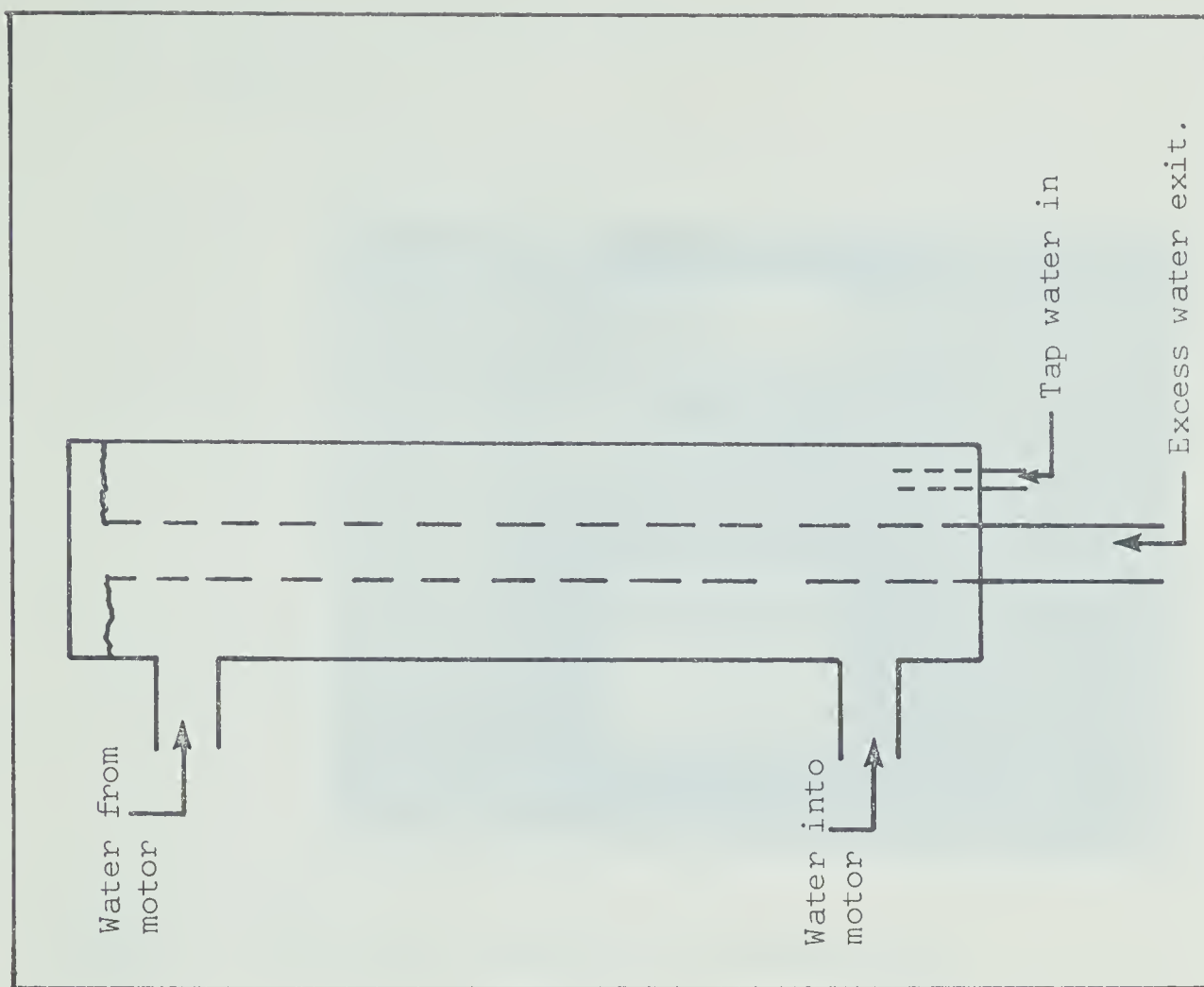


Figure 4: Schematic diagram showing cooling column.



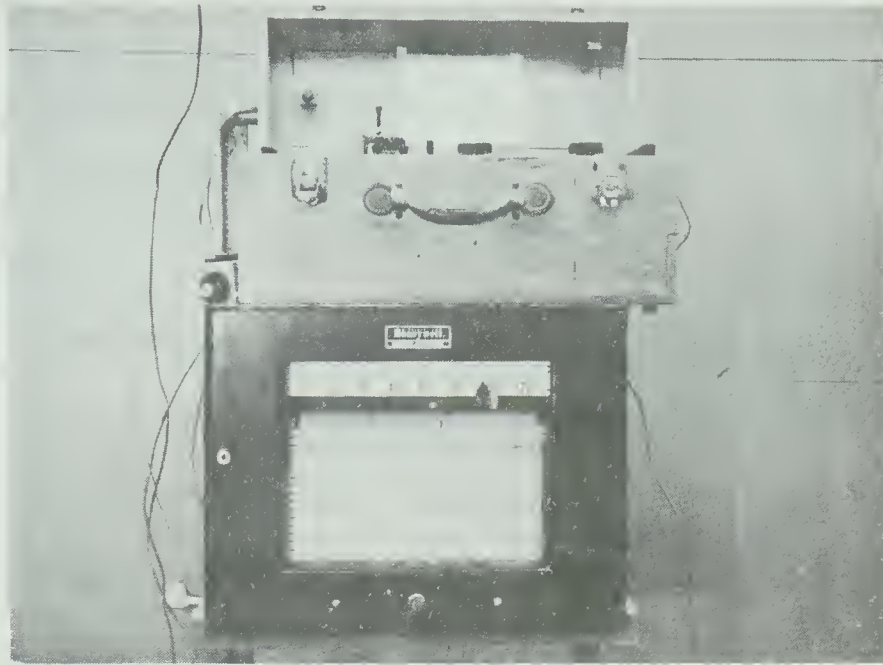


Figure 5: Honeywell recorder and potentiometer.



Figure 6: Sampling tube and thermocouple.







piece of plastic tubing from this pipe to the fuel pump.

#### 5.1.6 Strobotac

The motor speeds were adjusted by the use of a strobotac (figure 7), sighted onto the front drive pulley, to which a single piece of white masking tape had been affixed. This was a type 1531 Strobotac manufactured by the General Radio Company of Concord, Massachusetts.

#### 5.1.7 Dynamometer

The dynamometer (figure 8) used in the test runs for the purpose of applying loads, was manufactured by the Taylor Manufacturing Company of Milwaukee, Wisconsin. The dynamometer had a 15.750 in. torque arm and a constant of 4000, with maximum rpm being 7500. As described by the specifications supplied with the unit, the dynamometer is of the Hydraulic Absorption type, that is work is converted into heat, which is manifested by raising the temperature of the water passing through the machine (25). Continuous operation is obtained by replacing the heated water with unheated water at a rate commensurate with the amount of work being absorbed.

#### 5.1.8 Kinematic Viscosity Bath

This was the model "S" Kinematic Viscosity Bath built by Precision Scientific Company of Chicago, Illinois (figure 9). The bath conformed to the ASTM specifications (43) with a temperature uniformity of  $\pm 0.015$  Fahrenheit degrees throughout the temperature range of 68 F to 300 F. The bath was equipped with three heating elements of 250, 300, and 750 watt capacities, and a Precision Micro-Set Differential Range Thermoregulator. The thermoregulator had a very sensitive temperature contactor ( $\pm 0.005$  Fahrenheit degrees). In conjunction with the viscosity bath, Cannon-Fenske viscometers were used for the actual viscosity measurement.



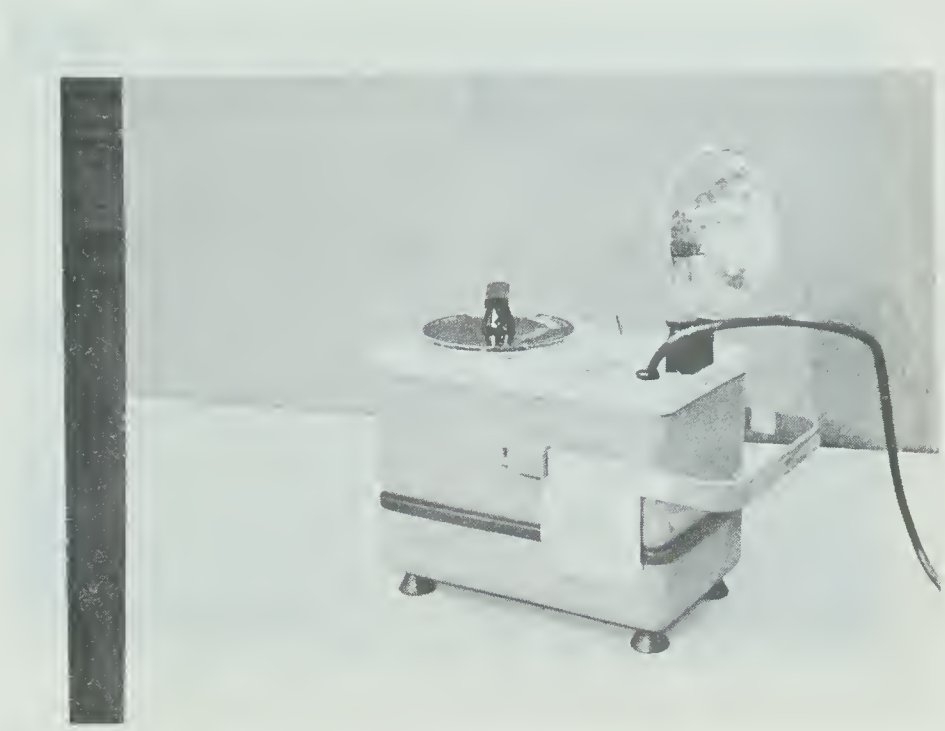


Figure 7: Strobotac.

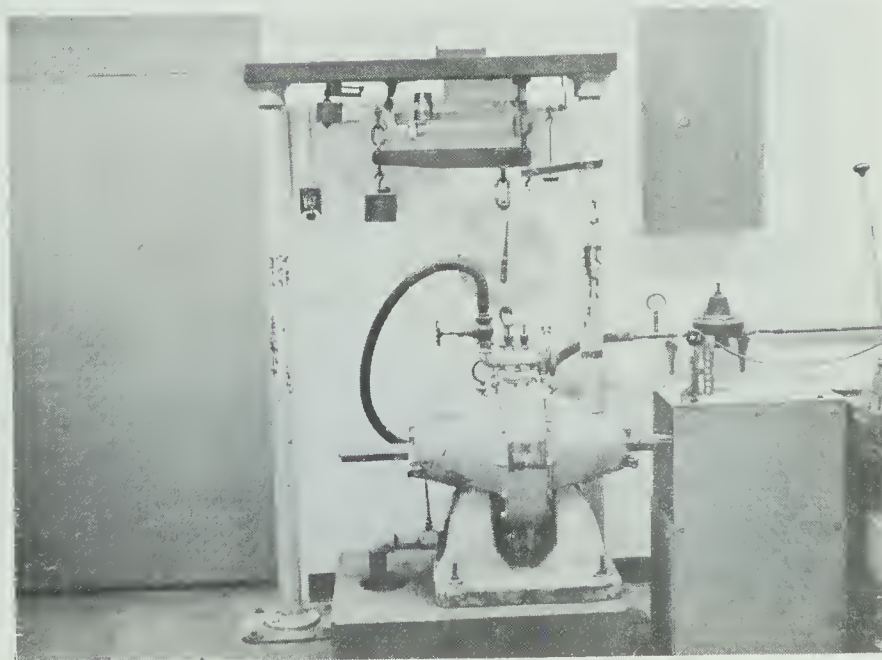


Figure 8: Dynamometer.



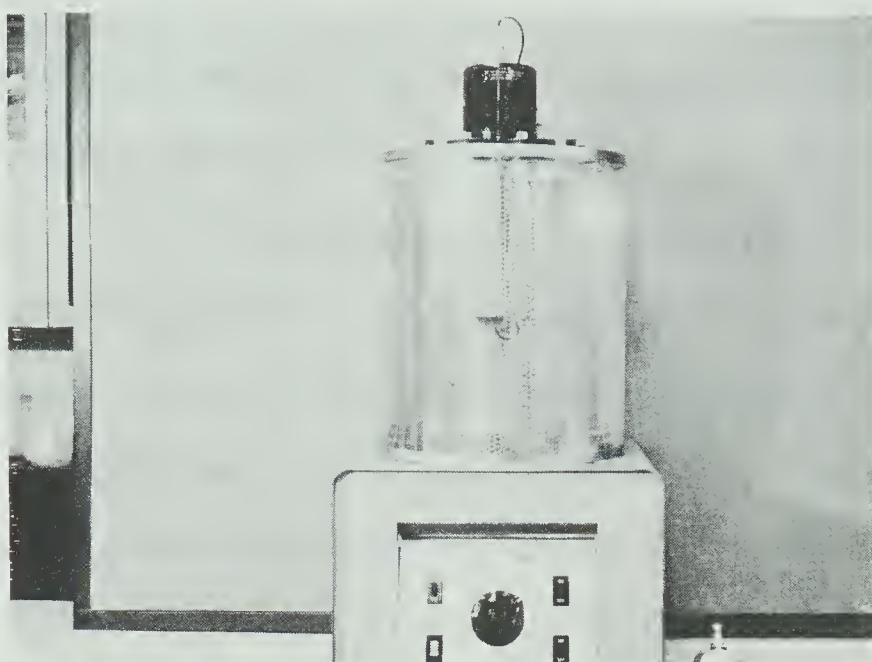


Figure 9: Kinematic viscosity bath.

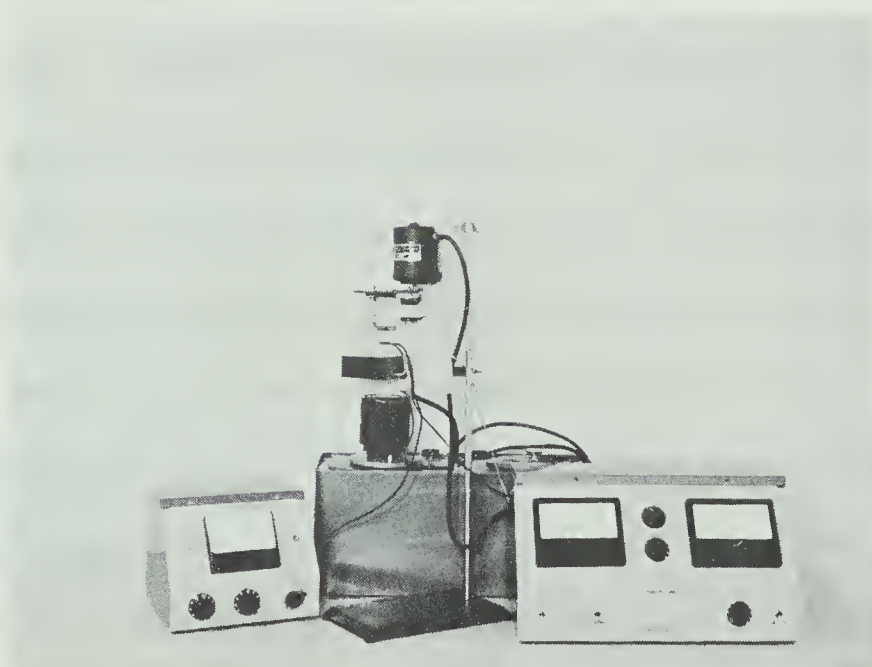


Figure 10: Cold-cranking simulator.



#### 5.1.9 Cold Cranking Simulator

Included in this general heading is the simulator mechanism, control console, and coolant circulator, all listed as Cold Cranking Simulator Model CCS1, and the Electronic Thermometer Model ET1 (figure 10). The simulator contained a three-quarter inch diameter by one-half inch long rotor, which rotated inside a thermostated stator. A series wound motor drove the shaft containing the rotor. The liquid to be tested filled the space between the rotor and the stator. A small tachometer generator, which developed a voltage in direct relation to its rotational speed, was connected in such a manner that the speed of the rotor could be measured. Stator temperature was maintained by the flow of cold methanol through a space between the stator exterior and the nylon mounting block. The control console consisted of an adjustable alternating voltage source and a current-regulated direct current supply for the simulator motor, a device for temperature control, and meters for measuring motor input and tachometer output(4).

The coolant circulator contained two insulated stainless steel reservoirs, one for dry ice and methanol, the other for methanol, a circulating pump, a solenoid valve and flow control valves. Methanol from the straight methanol side of the coolant circulator was pumped through the two valves, one acting as a partial bypass, and a spiral length of stainless steel tubing in the second reservoir to the stator. The two valves mentioned allowed the operator to adjust the ratio of the methanol that was cooled to that which was not, thus allowing more constant temperature control. The electric thermometer consisted of two glass-encapsulated bead thermistors, resistance bridge network, magnetic amplifier and microammeter(4). One thermister was placed







in the one-eighth inch diameter well nearest the front of the stator block and connected to the electromatic thermometer, while the other was placed in the other well and connected to the control console.

#### 5.1.10 Dilution and Water Contamination Apparatus

The two traps used in the crankcase dilution and water contamination tests are shown in figure 11. These conformed to the ASTM specifications required (39,44), and were used in conjunction with a 400 mm West-type condenser and a 1000 ml flask for crankcase dilution, or a 500 ml flask for water contamination (figure 12).

Heating was supplied by the use of a 300 watt heating mantle in conjunction with a zero to 140 volt variable transformer.

#### 5.1.11 Oxidation Products and Insolubles

The equipment used for these tests was very minimal, with the main items being several 30 ml medium textured sintered glass-bottomed crucibles, a 1500 ml filtration flask, a dessicator, and a forced air oven.

### 5.2 Materials

Three makes of oils were used along with five different grades. The three makes were Gulf, Imperial and Co-op, hereafter referred to as X, Y, and Z, and the five grades being 30, 5W-20, 5W-30, 10W-30, and 10W-40. Two different samples of Gulf 5W-30 were used and these will be referred to as X<sup>-</sup>5W-30 and X<sup>a</sup> 5W-30. Appendix V lists the properties of these new oils.

Two different grades of gasoline were employed to run the motor, these being regular grade or number two grade, as classified by Alberta Government Specification, Regular Grade and an aviation fuel, known as 80-87. Appendices I and II contain an analysis of these two fuels as carried out by the Research Council of Alberta Gasoline and Oil



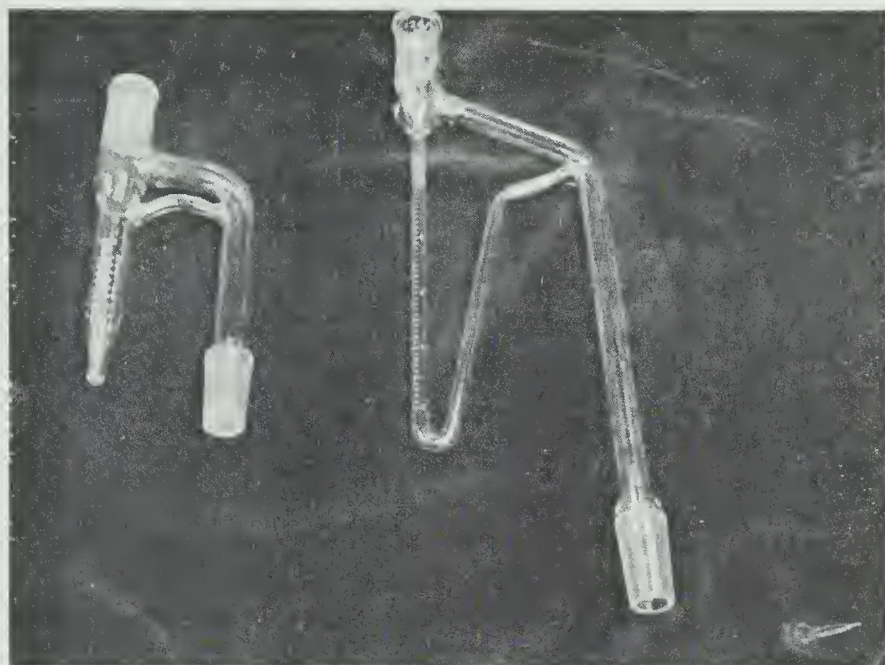


Figure 11: Fuel dilution and water contamination traps.

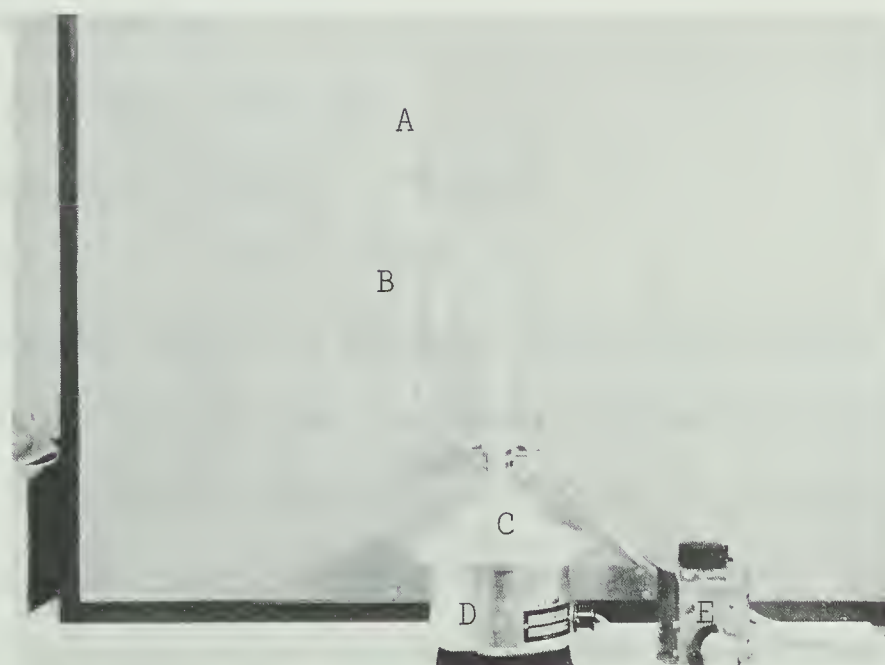


Figure 12: Fuel dilution test equipment showing: A - West type condenser, B - trap, C - flask, D - heating mantle, E - variable transformer.



Laboratory. Other materials used included methanol for the CCS, dry ice, mineral oil for the viscosity bath, and a various assortment of chemicals for cleaning purposes, oxidation products, and insolubles.

### 5.3 Engine Speed and Load Calculations

The author decided that three fairly common speeds representing city, intermediate, and country driving would be 30 mph, 45 mph, and 60 mph. Considering the flathead Ford engine, the common final drive ratios found in 1949 were 4.10:1, 3.90:1, and 3.55:1, that is when the ratio is 3.55:1 the motor will make 3.55 revolutions for every revolution of the rear wheel. A rear wheel diameter of two feet produces a distance travelled of 6.28 ft per revolution thus:

$$\frac{1 \text{ rpm of the wheel}}{1} = 6.28 \frac{\text{ft}}{\text{min}} = \frac{6.28 \times 60}{5280} = 0.0714 \text{ mph.}$$

Therefore, for 60 mph the speed of the wheel will be:

$$\frac{60}{0.0714} = 840 \text{ rpm.}$$

Thus, the motor must go

$$(840) \times 3.55 \text{ rpm} = 2983 \text{ rpm}$$

$$\text{for 30 mph -- } 1/2 (2983) = 1492 \text{ rpm}$$

$$\text{for 45 mph -- } 1\frac{1}{2} (1492) = 2237 \text{ rpm.}$$

These figures were also substantiated by the author's experience, as generally in a vehicle the tachometer reading was approximately fifty times the speed being travelled. That is, travelling at 60 mph, the motor would be going at approximately 3000 rpm.

Due to the odd numbers calculated above, a decision was made to run the motor at 3000, 2250, and 1500 rpm, which would fairly closely approximate 60, 45, and 30 mph.

Since the effects of load were to be incorporated into the results,





the problem arose as to what could be considered a load for the motor. Here, the results that Stonex (46) produced in 1949 were used. The hp values, interpolated from the curves, necessary to overcome wind and rolling resistance at the three speeds, were 31 at 60 mph, 17 at 45 mph, and 10 at 30 mph.

From these hp values, it was then necessary to work backwards from the dynamometer formula:

$$\text{hp} = \frac{\text{rpm} \times \text{lb}}{4000} \dots \dots \dots (12)$$

to get the pounds of load necessary to produce the appropriate hp values. This was done by rearranging equation (12) to get:

$$\text{lb} = \frac{4000 \times \text{hp}}{\text{rpm}} \dots \dots \dots (13)$$

When calculated, the loadings were 41.3 lb at 3000 rpm, 30.2 lb at 2250 rpm, and 26.7 lb. at 1500 rpm.

## 5.4 Methods

### 5.4.1 Preparations for a Run

The motors were made ready for the next day's run by one or two "flushes", after having drained for about 10 min, depending upon the circumstances. A flush consisted of putting two quarts of the oil to be tested into the motor and allowing the motor to run for 15 min. Only one flush was used if the next day's oil was the same as the last, whereas two flushes were used if there was to be a change in oil make or grade. The purpose of the single flush was to prevent the build-up of sludge occurring in the motor and thus interfering with viscosity measurement. In the case of two flushes, the second was done to ensure that one series of oil samples was not contaminated by another type of oil, thus resulting in possible erroneous results. As mentioned previously, the filters were not used on either motor, the reasons





being twofold:

1. increased complexity of the flushing operation as the filter would have to be removed and a new cartridge inserted.
2. addition of more space in which oil could remain to contaminate the next run.

This removal of the filter would not endanger the motor due to two reasons:

1. the length of a run was not long enough to warrant a large build-up of insolubles, and
2. the flush at the end of each run would further decrease the danger of high insoluble build-up.

During the period of the first flush, in the case of two flushes, or the flush in the case of one, the motor speed was adjusted and set for the next run. Similarly during this period the dynamometer was adjusted for the corresponding load.

At the end of the flush, or flushes, the motor was allowed to drain for approximately 30 min. In the case of the 292 Ford, the filter was removed, in addition to the pan plug so that this would drain as well. After this time interval, three quarts of oil of the type required for the next test run were put into the motor. The motor was then allowed to cool down overnight, a period of seven hours, so that all runs could be started from an approximately common temperature, that being 68 F. In the case of two flushes, the time interval for the drain period between them was 15 min.

#### 5.4.2 Making a Run

The motor was started, with the throttle and dynamometer



load having been set the night before. The speed was always less than that required for the run, but as the motor warmed up, a period of five to seven minutes, the speed increased to the preset value.

Throughout the run, at various time intervals, samples of the crankcase oil were taken and the speed of the motor was checked using the strobotac.

At the end of the run, the temperatures of the outlet water and oil in the pan were recorded. For the first 16 runs conducted, the temperature of the water and the oil were measured by a thermometer. The procedure was to measure the water temperature by holding the thermometer in the water cooler at the outlet pipe from the motor just before shutdown, and the oil by measuring the temperature of the oil in the pail immediately after draining. This procedure was soon found to be highly inaccurate due to several reasons: 1) uncalibrated thermometer, 2) oil temperature dropping immediately upon contact with the cool pail, and 3) measurement of the water temperature was in the cooler and not in the water jacket of the motor.

Due to these problems the author decided to employ thermocouples, with the potentiometer being used to increase the capacity of the recorder. Once this was built and calibrated, and the thermocouples had been inserted into the pan as well as into the water jacket, temperatures at the ends of the runs could be recorded accurately. Only the end temperatures were recorded since motor temperatures reached a constant value after 8 to 15 min from the start of the run.

#### 5.4.3 Sampling Procedure

Each time a sample was taken from the crankcase, the following procedure was followed. Firstly, an 80-ml sample was taken from the sampling tube (figure 6). This was done to remove any oil remaining



in the tube between the pan and the valve left from the previous sample, as well as to ensure that flow from the pan itself was initiated such that an actual crankcase sample was obtained. A 60-ml sample was then removed, at which time the valve was closed. The 80-ml sample that was taken to purge the sampling tube was then poured back into the motor via the oil filler. All of these volumes quoted above were not exact but were within  $\pm 10$  ml, which was felt to be close enough for actual sample size was not crucial, other than to provide enough to test. At the end of each run, the same purging technique was again employed, but the sample size taken was 300 ml, thus giving a sufficient quantity in order that crankcase dilution tests as well as other tests could be made if necessary.

#### 5.4.4 Oxidation Products and Insolubles Measurement

The method used for testing of the oil samples for insolubles and oxidation products was that used by the Research Council of Alberta Gasoline and Oil Laboratory rather than that given by either ASTM method D893, which records the pentane and benzene insolubles as a percentage after centrifuging and then weighing, or by ASTM D91, in which centrifuging is also carried out. The reasons for this abandonment of ASTM test methods here was three fold: 1) lack of equipment, 2) ease of operation without a large sacrifice in quality, and 3) recommendation by the Gasoline and Oil Laboratory on the basis that this was the test they used for all their work.

The test involved firstly packing a sintered glass-bottom crucible with about 4 gm of Hyflow Super-Cel, washing with ASTM precipitation naptha, and drying in an oven at 90 C to 100 C for one hour, at which time it was weighed. A 10-gm sample of oil was then weighed out into



an Erlenmeyer flask and was diluted with 100 ml of flocculant and left to stand for one hour. The flocculant consisted of 50 ml of N-n-Butyldiethanolamine in 1000 ml of precipitation naptha. The contents of the Erlenmeyer flask were filtered through the crucible and then washed with 100 ml of precipitation naptha. The crucible was dried as before, and weighed. The crucible was then washed with 100 ml of chloroform, dried and weighed again. The results were such that naptha insolubles represented the oxidation products plus insolubles (carbon, dirt, and other inorganic materials), whereas the chloroform solubles represented the oxidation products. The results were then reported as a percentage of the original sample as being either oxidation products or insolubles.

The methods used for the running of the CCS, the measurement of kinematic viscosity, the measurement of fuel dilution, the measurement of water present in the crankcase oils, and the API gravity were all done in accordance with the correct ASTM method (38,39,43,44,50).

#### 5.4.5 Volatility and Fuel Dilution Tests

Four 200-ml samples of X 5W-30 were mixed with an appropriate amount of gasoline to give dilution percentages of one, two, two and one-half, and three percent. Viscosities of these oils were then measured at 0 F, 100 F and 210 F.

For the comparison of volatility, samples of X 5W-30, Y 5W-30, and Z 5W-30 were heated at  $250\text{ F} \pm 10$  Fahrenheit degrees for extended periods of time. Samples were taken and weight losses recorded at time intervals sufficient to enable a plot of changes occurring to be made. Viscosity measurements were then made on these samples at 0 F, 100 F, and 210 F. Although this did not follow the ASTM method (40),







for the test of volatility, the procedure was devised so as to give some idea of the comparable volatility among these three oils.

#### 5.5 Sampling Intervals and Run Lengths

Initially, a trial run was made with samples being taken at 1/2, 1, 1 1/2, 2, 3, 4, 6, 8, 10, 12, 14, and 16 hours from the start of the run. The second run consisted of a total time of 30 hours continuous running, with samples being taken at 1/2, 1, 1 1/2, 2, 3, 4, 6, 8, 10, 12, 15, 19, 24, and 30 hours.

As the trials progressed 16 hours was found to be a sufficient length of run to give fairly good results and also fitted well into two eight-hour working shifts. The samples were gradually taken less and less frequently, till by the twentieth run, only nine samples were taken, these being at 1/2, 2, 4, 6, 8, 10, 12, 14, and 16 hours. Also interspersed among these so-called "maximum sampling" runs were seven "minimum sampling" runs during which samples were taken at 4, 10, and 16 hours. These were done to see if the results of the removal of large quantities of oil (13x60 ml = 780 ml) would affect the viscosity change characteristics.

Throughout the entire length of testing, an attempt was made to make the runs fairly random, such that there was not a long series of runs conducted at one speed in a row, but that runs of the same speed with minimum or maximum sampling methods, were close enough so that motor condition would not have changed excessively, thus invalidating the comparison. A complete listing of the runs in their order of occurrence, along with the speeds, sampling times, and other details can be found in Appendix III.



## 5.6 University Service Vehicles

To complement the series of runs made in the laboratory, samples were collected from university service vehicles. These samples were tested for fuel dilution and those greater than or equal to two percent were discarded. The use of this value was based on two reasons:

1. Domier's (8) conclusions that this was a reasonable value, and
2. the results obtained from the fuel dilution tests, as given in section 6.3.3.

Oil was generally changed in the vehicles at two-month intervals, regardless of mileage, hence a wide variation in the number of miles serviced by these oils.



## 6. RESULTS AND DISCUSSION

### 6.1 Effects of Loading and Sampling

Figures 13 to 16 and the data given in Appendix VI show the effects of load to be minimal. Before a discussion of the above can be given two points should be mentioned. Firstly, two runs, 7 and 13, did not complete the full sixteen-hour time interval due to a shortage of the oil in the crankcase, causing the oil safety switch to shut the motor down at 13 and 14 hours respectively. This problem was remedied by reducing the number of samples taken during a run and by correcting an oil leak occurring at the fuel pump.

Considering the viscosities at 210 F, the greatest difference that occurred between a loaded and unloaded run was 0.25 cs. The data in Appendix VI shows that at 2250 rpm and 3000 rpm, the loaded run had a lower viscosity than the unloaded run, whereas for the 1500 rpm run, the opposite occurred. Thus an assumption could be made that somewhere between 1500 rpm and 2250 rpm, a transition occurred, that being a speed at which there was no difference between a loaded and an unloaded run with respect to viscosity change. The viscosities at 0 F and at 100 F for the 1500 rpm speed show that the values for the loaded run were lower than for the unloaded run. This result would suggest a transition in the temperature measurement direction as well, that being a temperature between 210 F and 100 F for the 1500 rpm run at which viscosities would become identical. This, of course, could not be shown to be fact with the data presented here; theorization only was possible, with further work being required to either prove or disprove the theory.



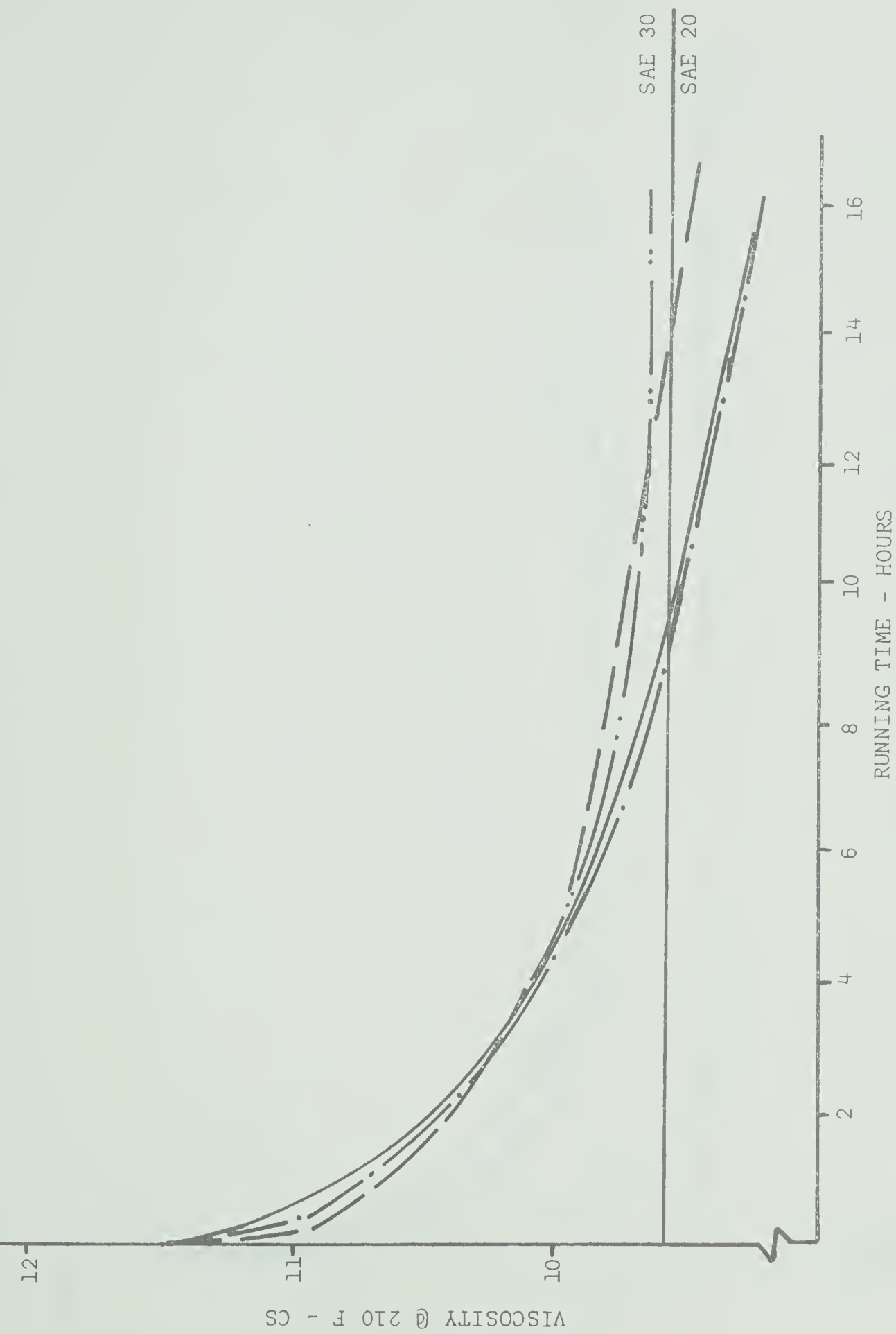


Figure 13: The effects of load and sampling on viscosity (210 F) at 1500 rpm.





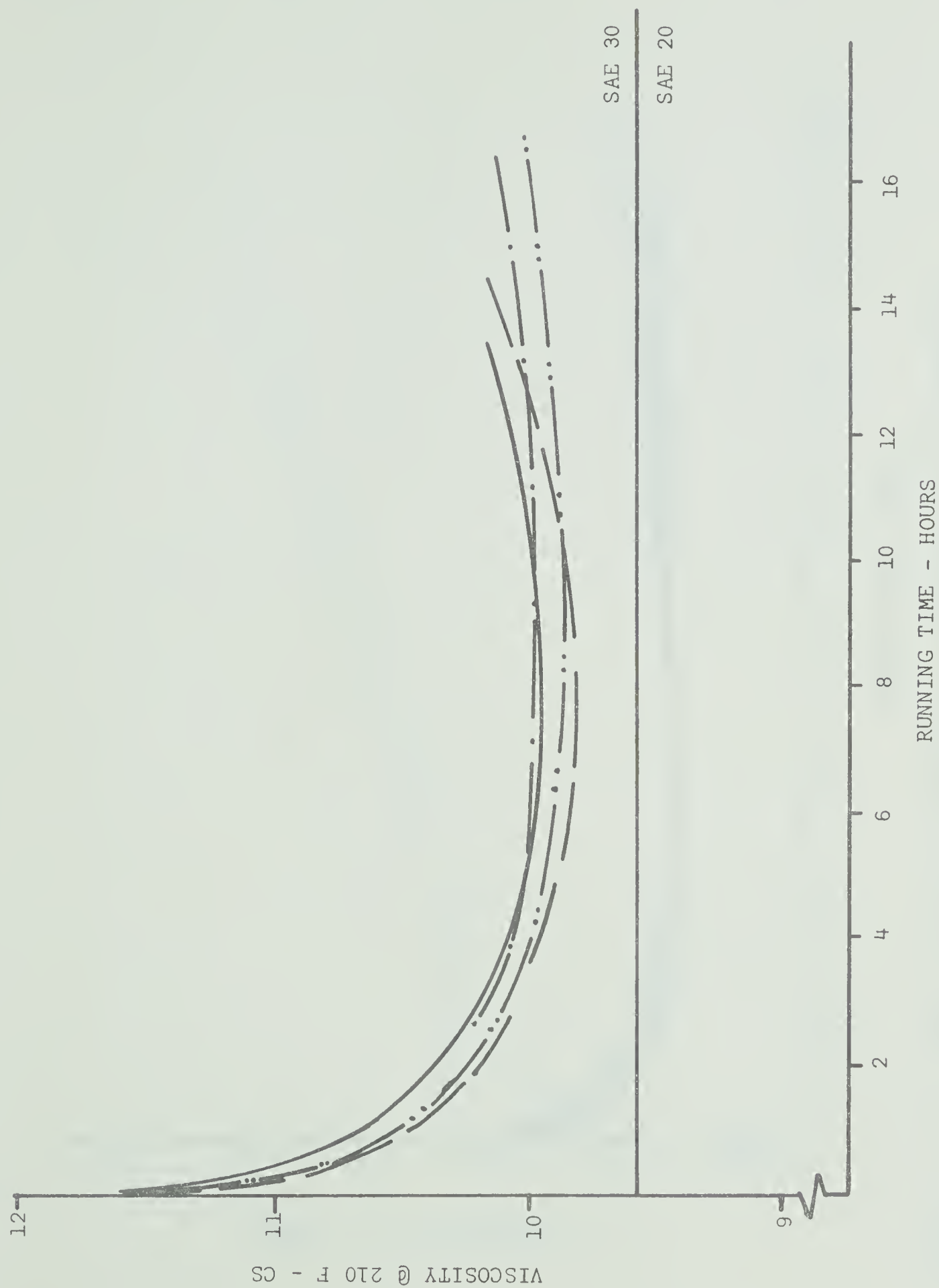


Figure 14: The effects of load and sampling on viscosity (210 F) at 3000 rpm.



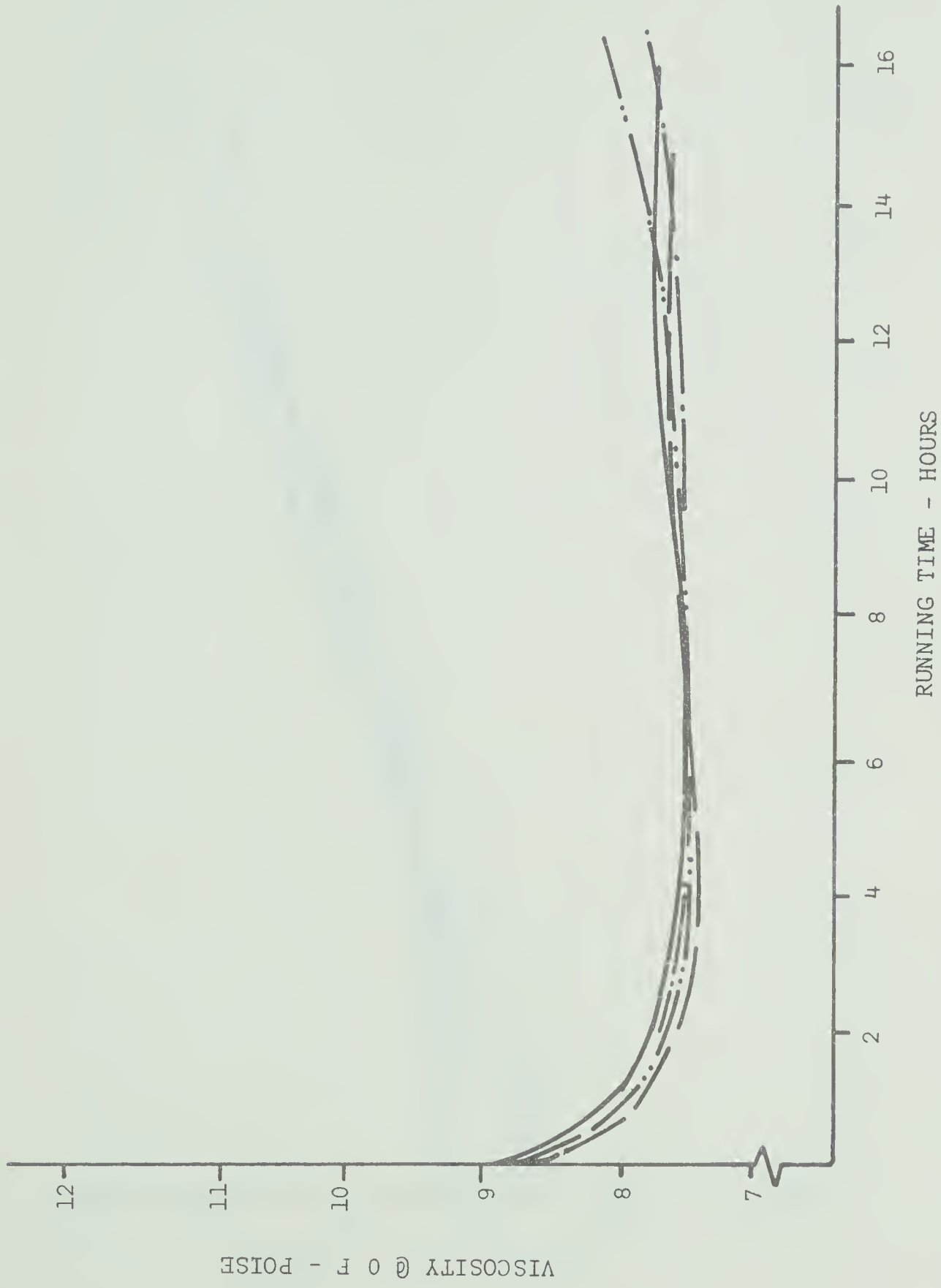


Figure 15: The effects of load and sampling on viscosity (0 F) at 1500 rpm.



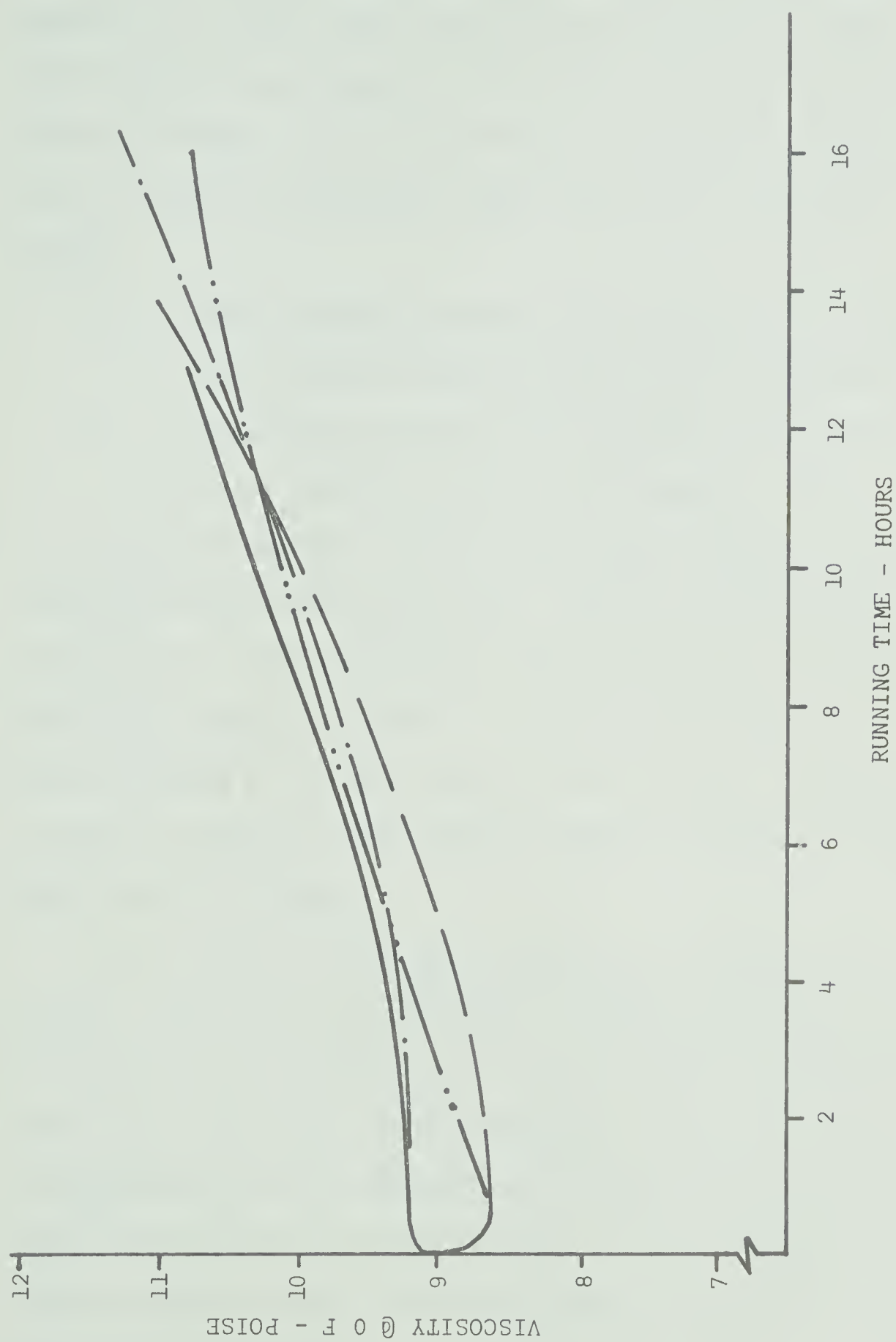


Figure 16: The effects of load and sampling on viscosity (0 F) at 3000 rpm.



One of the conclusions that was drawn from the effects of loading was that as a load was applied, the viscosities became somewhat lower, possibly due to more stress being placed on the motor, which in turn caused higher shear stresses to be placed on the oils used. This might have been brought about by a reduction in clearances in which the high rates of shear were produced. These reductions could be due to two factors:

1. higher operating temperatures (Appendix IV) attained when a load was applied causing slight expansions, or
2. slight eccentricities in the bearings being increased due to the motor having to work against a load.

This might then explain the transition effect theorized earlier as occurring between 1500 and 2250 rpm. That is, proportionately, the load applied at 1500 rpm was less than that applied at 2250 rpm, hence less shear stress was produced. In addition motor operating temperatures were not raised to the same extent at 1500 rpm (nine Fahrenheit degrees average) as compared to 2250 rpm (18 Fahrenheit degrees average) by the application of the load.

If the effects of sampling technique are considered at 0 F, 100 F and 210 F the curves for minimum and maximum sampling for the same load and speed setting intertwine and in several cases lie directly upon each other. Thus this ruled out the assumption that due to high oil removal, the remaining oil was circulated more frequently and was sheared more often, thus producing greater viscosity loss than would be found in service conditions where no oil was removed, thus contradicting the work of West and Selby (55).





## 6.2 Effects of Speed

Figures 13 to 18 show the effects of speed to be appreciable. In many instances the final viscosities, at 210 F, were found to be higher at 3000 rpm than at 1500 rpm, with a definite upswing occurring in many of the curves, thus showing a thickening of the oil when run at higher speeds. In a few cases, no upswing was found but the viscosity of the oil run in the motor at 1500 rpm was dropping more rapidly than that at 3000 rpm. Thus, although this was not a physical upswing of the curve, the same result was implied, but to a less severe degree. In the case of Y 5W-30 and Y 10W-40 oils, run in the 292 Ford, no upswing was found but both curves were falling at the same slope after approximately six hours of running. This produced two parallel lines, which still was essentially the same results, that is instead of a greater viscosity drop at 3000 rpm as compared to 1500 rpm there was an equivalent drop, this being in disagreement with previous work (55).

In all cases the end viscosities, at 0 F, of the higher speed runs were larger than those at the lower speeds. The 100 F viscosities, as was expected, were a transition between 0 F and 210 F, that is in all cases except Y 5W-30 and Y 10W-40 the final viscosities of the higher speed runs were greater than those of the lower speed runs. In the case of Y 5W-30 and Y 10W-40, although the viscosities were lower for the high speed runs, there was less of a difference between them on a percentage basis at 100 F than at 210 F. That is for Y 5W-30, 8.1 percent at 100 F and 12.8 percent at 210 F and for Y 10W-40, 4.2 percent at 100 F and 8.3 percent at 210 F. Thus this follows the same general trend that as temperature of viscosity measurement decreased viscosity



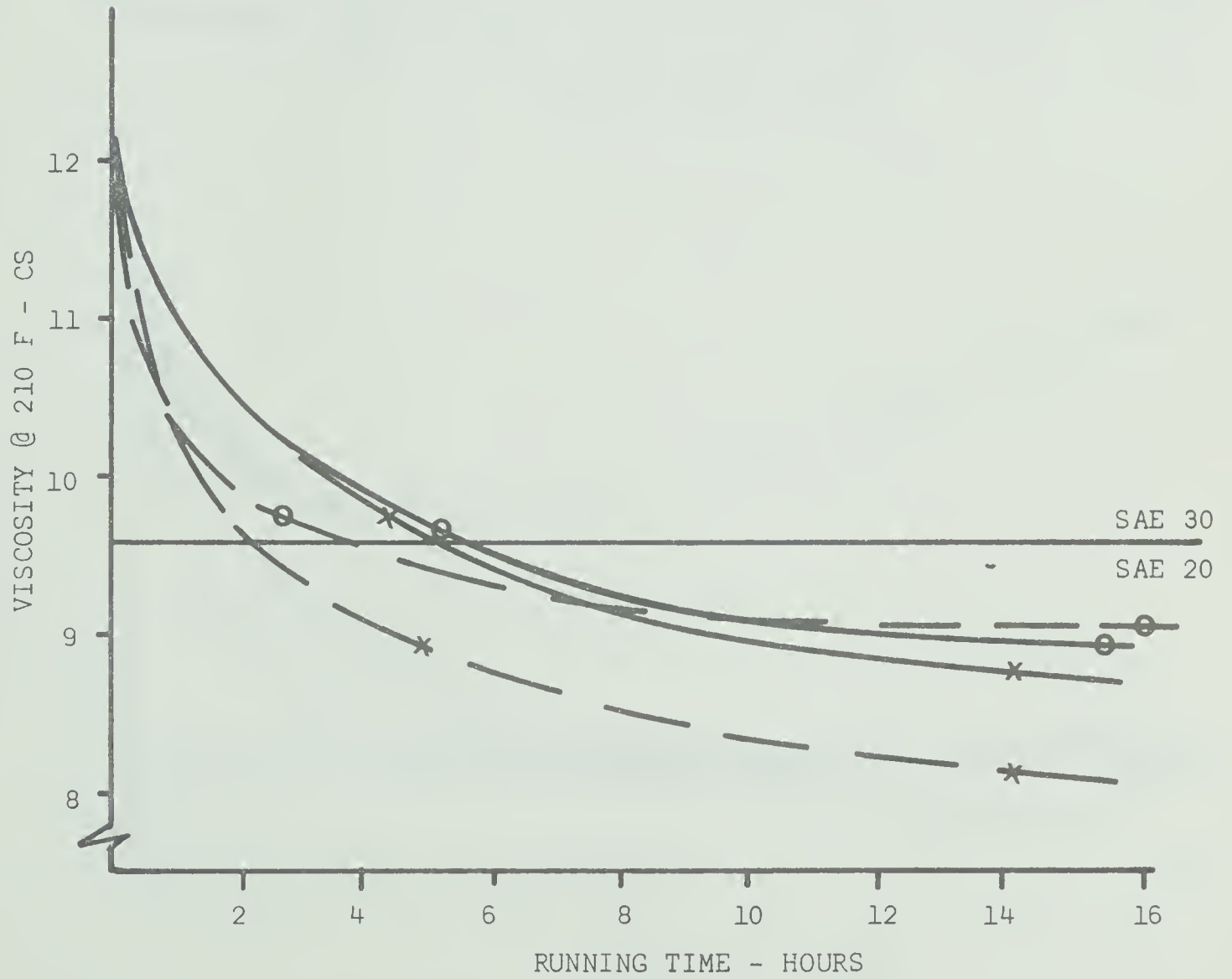
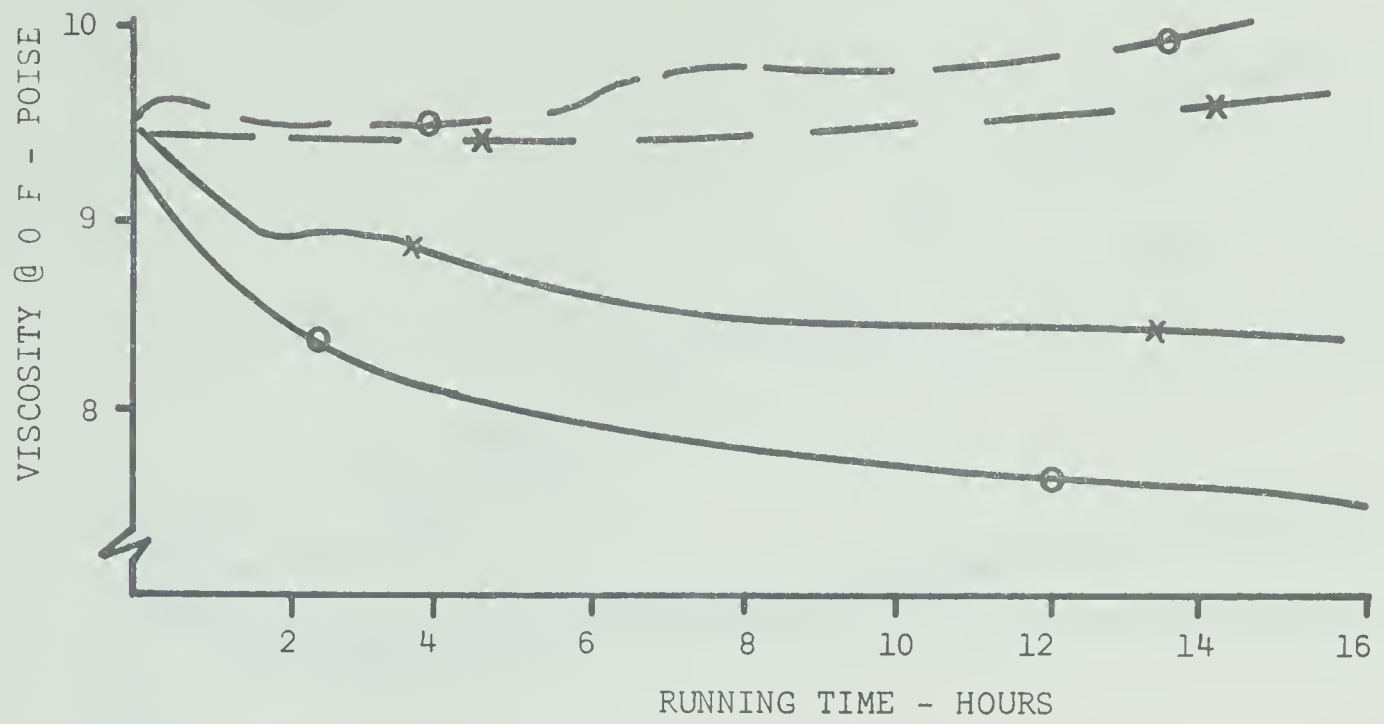


Figure 17: The effect of speed on viscosity (0 F and 210 F) for oil Y 5W-30.



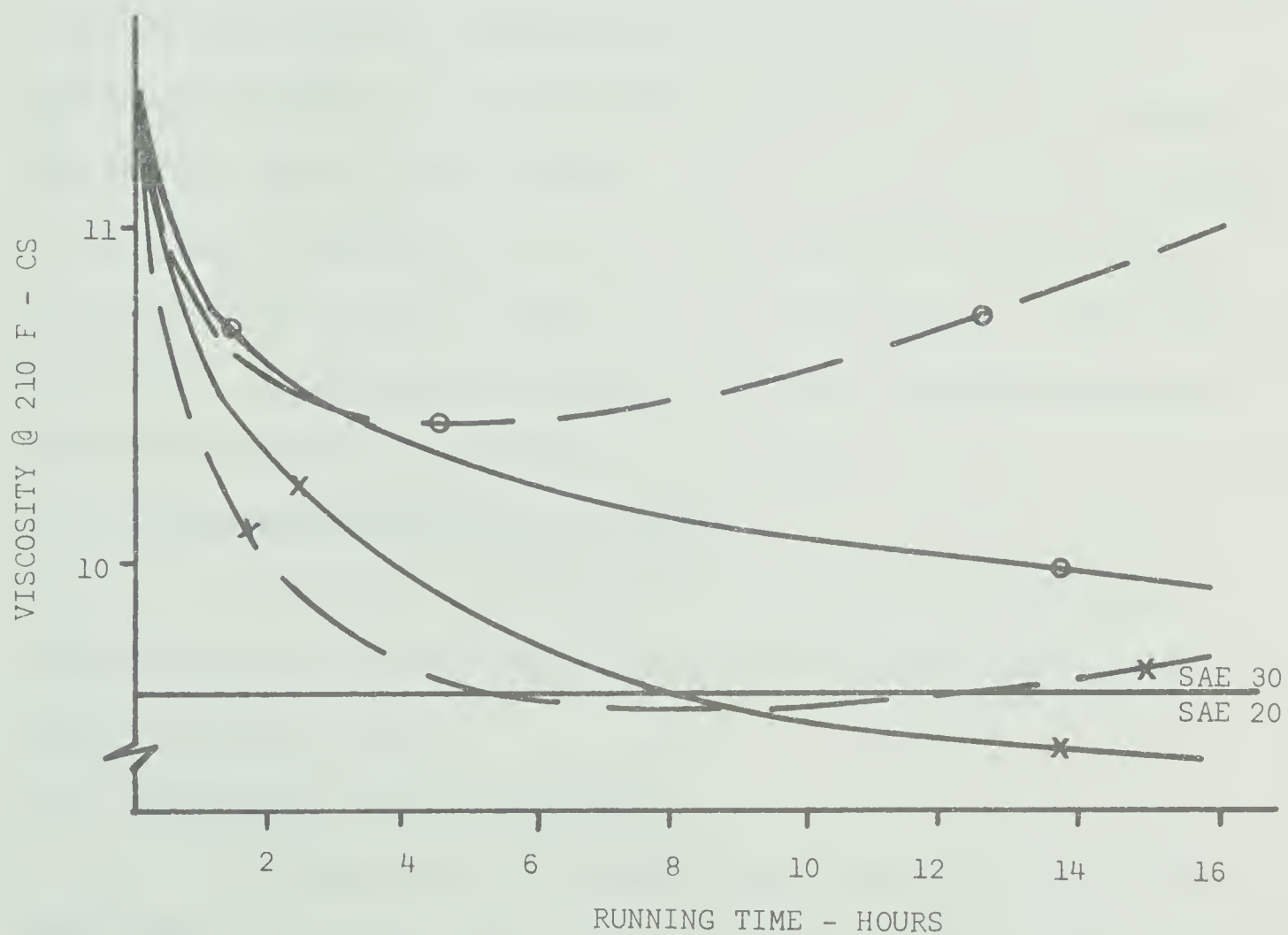
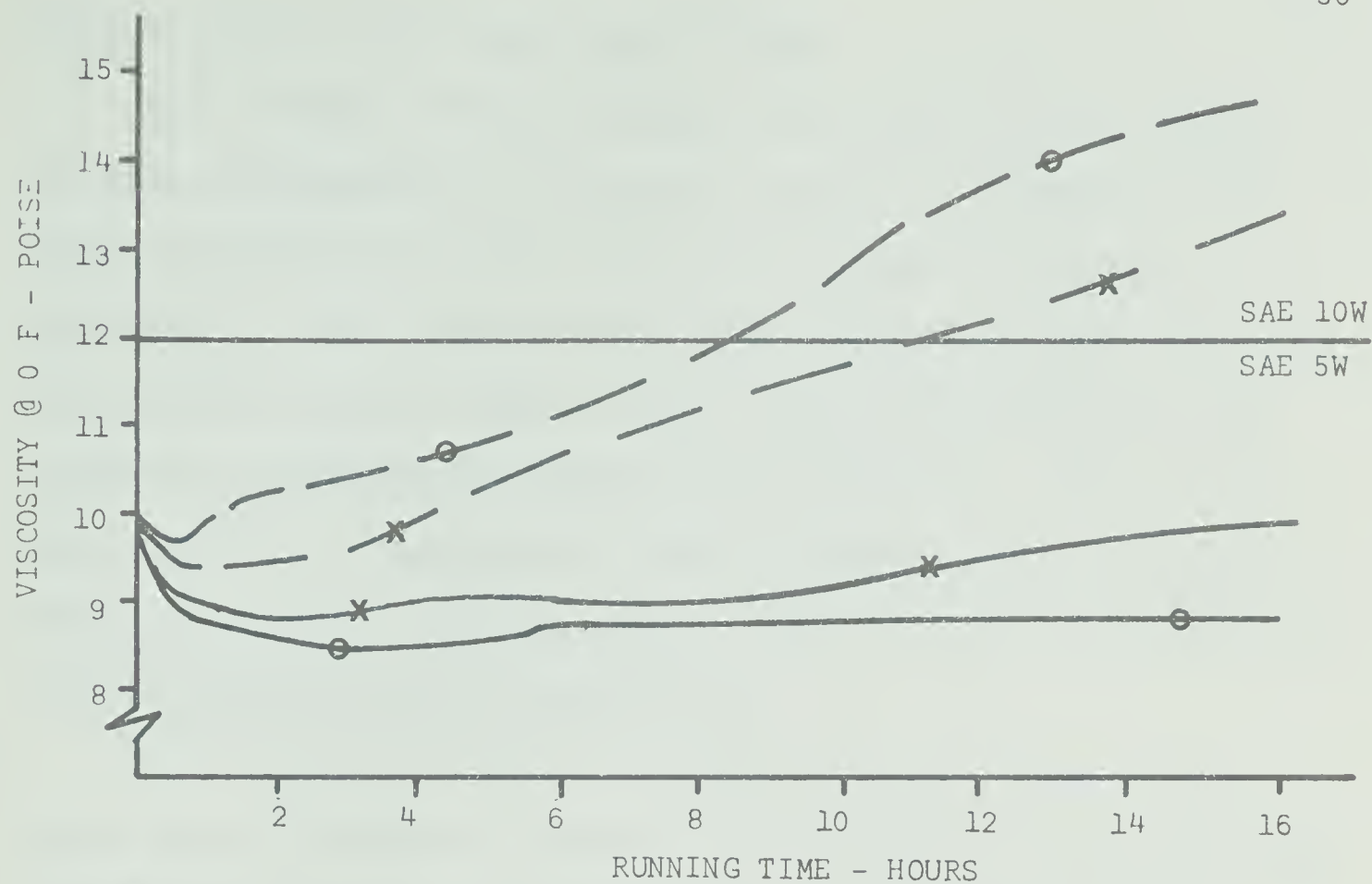


Figure 18: The effect of speed on viscosity (0 F and 210 F) for oil Z 5W-30.



losses at 3000 rpm were less than 1500 rpm.

From a polymer shearing standpoint, this cannot be the case due to the pure mathematics of the problem, that is the higher the motor speed, the greater the shear rates and the greater the polymer degradation. Thus, there must have been some other factors influencing the viscosity change to such an extent that polymer degradation was equalled or exceeded by a viscosity increasing agent. These factors were thought to be lead deposits from the gasoline used, insolubles, oxidation products, crankcase dilution, and volatility of the base oil used in formulating the multigraded oil.

At this point the differences between the three makes of oils used should be mentioned in respect to this upswing. It was found that in all cases where the same speed and motor were considered for a particular SAE grade, oil Z was affected the most, oil Y was affected the least, and oil X was in between. That is, as can be seen in figures 24 to 29, and in Appendix VI, oil Z had the greatest upturn; oil Y, on the other hand, had the least, if any, actual upturn. This effect can be seen at all three viscosity measurement temperatures where the lower the temperature the greater is the effect.

### 6.3 Factors Affecting Viscosity Changes

Following is a discussion of the factors affecting the results for the SAE 5W-30 oils used, although the same would apply to the other grades tested.

#### 6.3.1 Tetraethyl Lead Contamination

To investigate this possibility, two runs, 18 and 19 were made using a low leaded fuel. Before these were made the motor was run for several periods of time on this fuel and flushed following





each to remove any lead deposited previously. Appendices I and II show that the aviation 80-87 fuel had a lead content of 0.70 gm/IG whereas the regular grade fuel had a 1.26 gm/IG concentration or almost twice as much lead. The results of these two runs are given in Appendix VI. In each case the low leaded gas runs had less of a viscosity loss than did either of the comparable high leaded gas runs (7 or 9), thus essentially eliminating the lead contamination as being responsible for the upswing. Since this factor proved to be unimportant further testing was deemed unnecessary.

#### 6.3.2 Oxidation Products and Insolubles

The second factor considered was that of oxidation products and insolubles. Vick and Goodson (53) showed that a viscosity increase was not observed until the insolubles content was in excess of five percent (high speed centrifuge method). In regards to oxidation effects the authors found that the effect of oxidation depended on the new base oil viscosity. That is, the viscosities of the heavier oils decreased, whereas the viscosities of the lighter oils increased, the zero point occurring at a new base oil viscosity of 7.5 cs at 210 F. Applying the above criteria to this research work, no upswing due to insolubles should be found, due to the fact that the highest insoluble content observed was 1.81 percent. Of course the two methods used to obtain the insolubles content were different, with the method for this research work being slightly less accurate but not to such an extent that only one third of the actual insolubles would be found. If the oxidation products are to be considered using Vick and Goodson's criteria, base oil viscosities would have to be known for each of the oils. Thus using this criterion in reverse the base oils should be



thickest for the Y oils and thinnest for the Z oils, if however, this does not hold either the criterion is wrong or oxidation products are not an influencing factor.

In considering the results of the oxidation products and insolubles as listed in Appendix VII, several points should be brought out. In every case except for oil X 5W-30 run in the flathead Ford the oxidation products were greater at 3000 rpm than at 1500 rpm. The difference, however, was usually less than 0.05 percent with the greatest being 0.28 percent. In the case of insolubles all were larger at 3000 rpm than at 1500 rpm except for the case of oil Y 5W-30 run in the 292 Ford. Here the differences were slightly more, with the largest being 0.36 percent and the average being approximately 0.15 percent. These relatively small differences could not conceivably produce the large differences in viscosities observed between the two speeds. To further substantiate this, if the Y 5W-30 and Z 5W-30 oils are considered (that is the one least affected as compared to the one that is most affected) the insolubles and oxidation products are at least equal and for several of the runs the Y 5W-30 oil has higher values. Furthermore, if a comparison is made between a loaded and an unloaded run for the same speed, the loaded run was found to have insolubles content and oxidation products content approximately twice that of the unloaded run. If, then, insolubles and oxidation products were such a critical factor, the curves shown in figures 13 to 16 for the two speeds should have been vastly different. However, the two curves, in all cases, were approximately parallel rather than diverging with the viscosity of the loaded run increasing much more rapidly. Apparently, although insolubles and oxidation products have an effect, it is very questionable



as to whether this can account for the results observed.

### 6.3.3 Crankcase Dilution

Appendix VII gives the fuel dilutions as measured from the end samples for several representative runs. These results showed that as motor speed was increased or as a load was applied fuel dilution decreased. This lower dilution was due to the higher operating temperatures at which the motor was running, hence any fuel that was getting into the crankcase was evaporated more readily. These results tended to explain the greater viscosity drops found at the slower operating speed, for the higher the fuel dilution the less would be the viscosity. To investigate whether the fuel dilution effects were great enough to cause this viscosity difference the dilution tests were conducted. Appendix IX gives the results of these tests, while figure 19 shows the viscosity changes on a percentage basis. From this figure two things can be noted: 1) the oil appeared to have a two percent tolerance level to fuel dilution, for beyond this value the viscosities dropped rapidly, 2) as the temperature of viscosity measurement decreased the effects of fuel dilution increased.

Since the dilution effects were studied for the X 5W-30 oil, only this make and grade could be considered in the calculations following, however the results are representative of all the oils.

The viscosity difference at the ends of runs 9 and 14 at 210 F was 0.85 cs. Run nine had a dilution of 0.8 percent thus the viscosity should be only 98 percent of the undiluted value as seen in figure 30. This would cause the undiluted viscosity to become  $10.10 \text{ cs} / .98 = 10.31 \text{ cs}$ .

Similarly, for run 14 the viscosity would become  $9.25 \text{ cs} / .965 = 9.59 \text{ cs}$  leaving a difference of 0.72 cs. Similar calculations were carried out for runs 16 and 17 as well as for all four runs at 0 F. The results



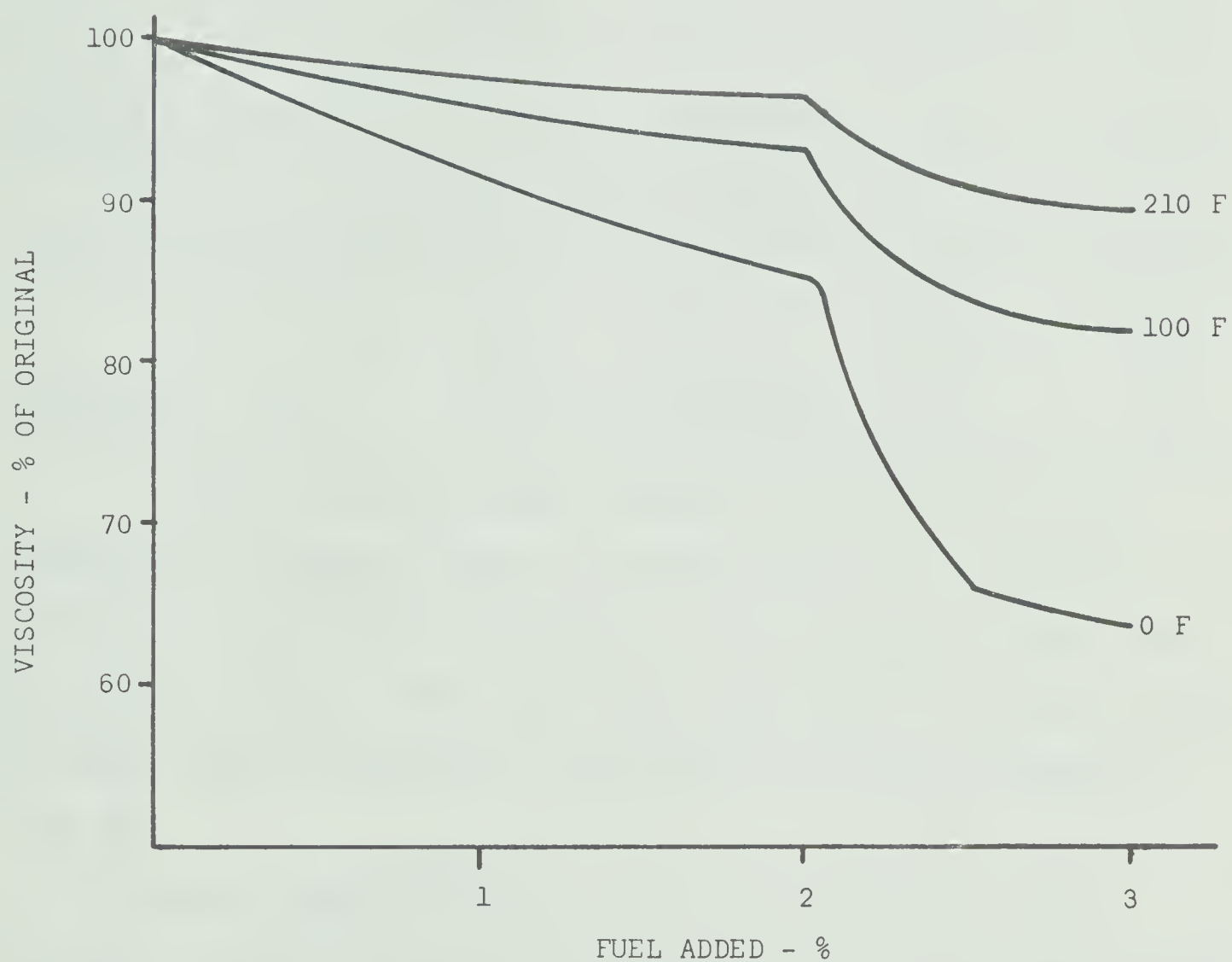


Figure 19: The effect of fuel dilution on viscosity (0 F, 100 F and 210 F) for oil X 5W-30.





are tabulated below:

TABLE 3: VISCOSITIES CORRECTED FOR DILUTION

210 F Viscosities (cs)					
Run No.	Uncorrected	Corrected	Run No.	Uncorrected	Corrected
9	10.10	10.31	17	10.00	10.24
14	9.25	9.59	16	9.66	9.98
Difference	.85	.72	Difference	.34	.26
0 F Viscosities (poise)					
9	10.80	11.59	17	11.20	14.23
14	7.75	9.06	16	8.10	9.19
Difference	3.05	2.53	Difference	3.10	3.24

In three of the four cases considered the difference in end viscosities decreased but none to the extent that the viscosity at either 0 F or 210 F for the 3000 rpm run became smaller in value than for the 1500 rpm run. This would dispel the effects of dilution as being the major cause for the lower viscosities at 1500 rpm as compared to 3000 rpm.

This data does not present an accurate indication of what happened, for the dilution tests set up to determine percentage viscosity changes used new oil in the mixture, whereas for the calculations done, used oil was considered. In addition, figure 30 is questionable as only four points were used in plotting, nonetheless a rough approximation of the effects of dilution are given.

#### 6.3.4 Volatility of the Base Oil

The last effect considered was the possible evaporation of the lighter ends of the base oil used in the formulation of the multi-



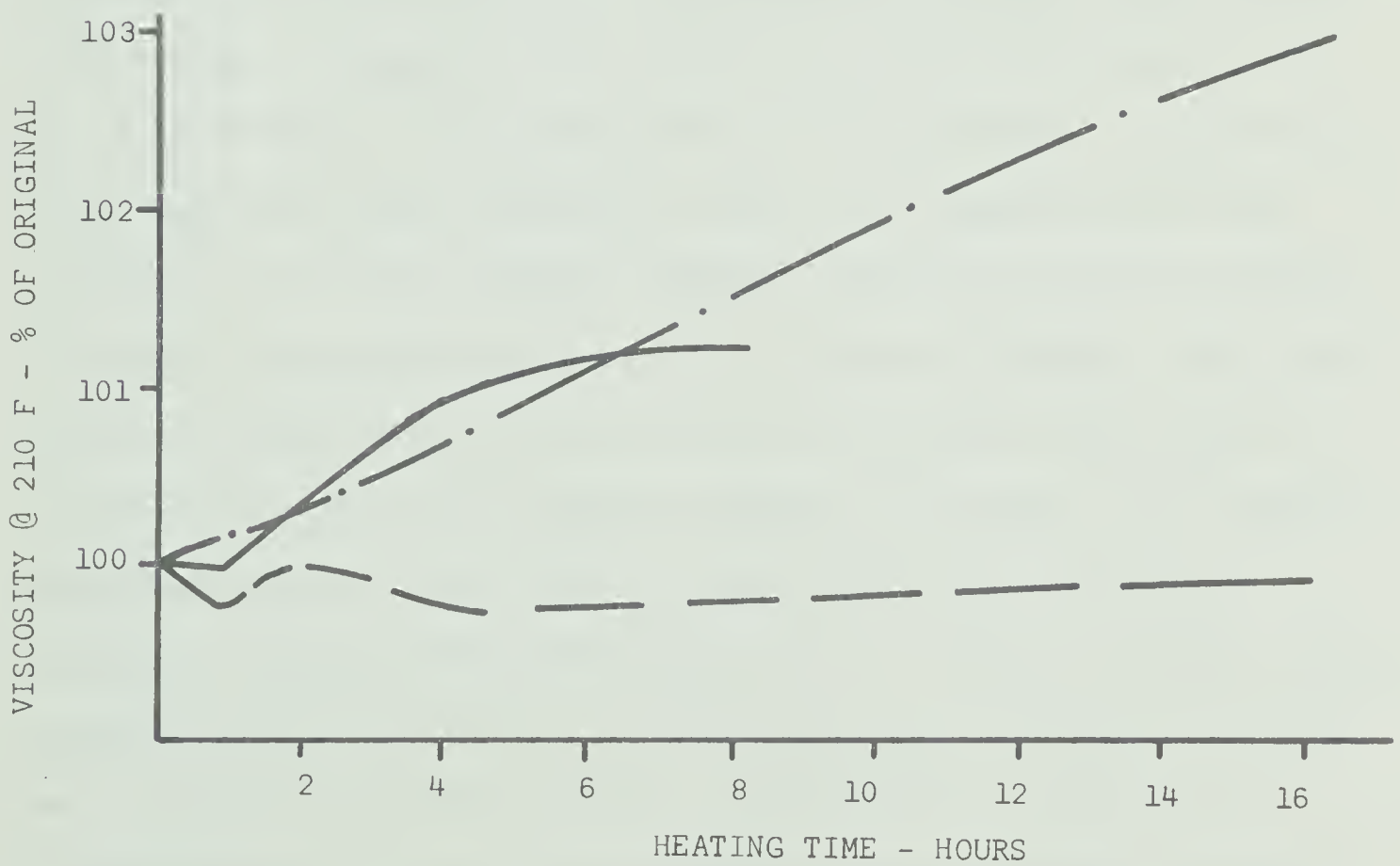
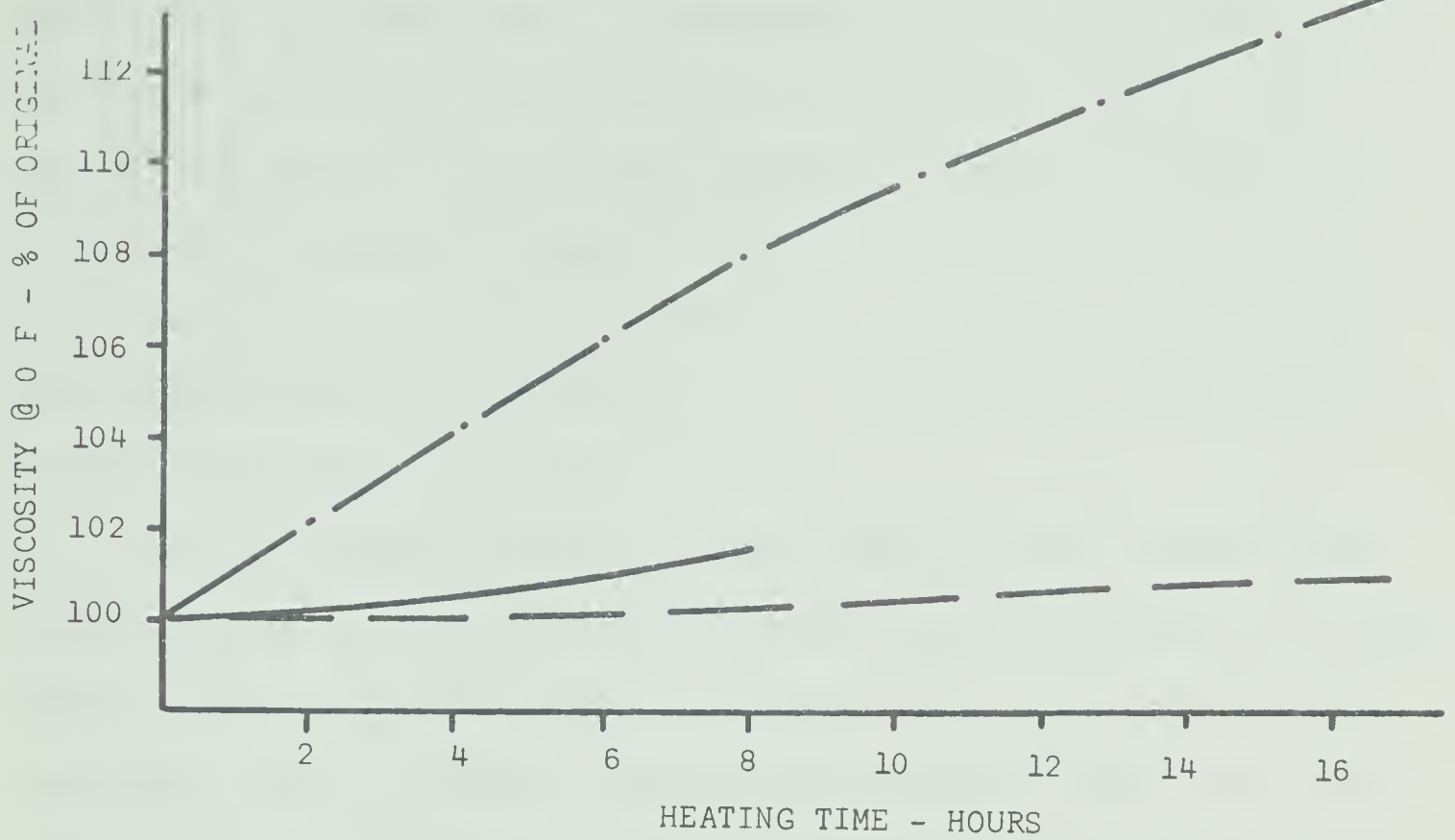


Figure 20: The effect of heating (volatility studies) on viscosity (0 F and 210 F) for three SAE 5W-30 oils.



graded oil. For these tests the temperature to which the oil was heated was arbitrarily chosen as  $260\text{ F} \pm 20$  Fahrenheit degrees. This was not considered to be an extreme temperature found in the operating motor, as pan temperatures reached  $220\text{ F}$ , thus indicating other parts of the motor would be well in excess of this. In addition, Gruse (13) gave temperatures of an operating motor as being in the range of  $200\text{ F}$  to  $450\text{ F}$ , dependent on the area considered.

During volatility tests the beaker containing the oil was neither stirred nor agitated, nor was any air forced over the surface of the oil. This was done to further lessen the severity of the test such that any conditions found in the motor would produce a greater effect than found experimentally. Upon plotting the values found in Appendix X, a definite difference in weight losses, on a percentage of original weight basis, can be seen. The greatest loss occurring in oil Z 5W-30, the least in oil Y 5W-30 with X 5W-30 lying between. If the changes in viscosity at  $210\text{ F}$  are then plotted (figure 20), oil Y 5W-30 remains essentially constant, oil X 5W-30 increases somewhat, whereas oil Z 5W-30 increases three and three-quarters percent after 19 hours of heating. This figure shows the same results at  $0\text{ F}$ , only on a more drastic scale with the Z 5W-30 oil having a 12.5 percent increase in viscosity. On a relative basis these results would tend to explain the amount and order of viscosity increases obtained for the oils, X, Y, and Z. Secondly, these results possibly explain why the 3000 rpm viscosity values were higher when compared to the 1500 rpm runs, or exhibited an upturn in the curves (figures 13 to 18). This would be due to the higher operating temperatures found during the 3000 rpm runs, causing greater evaporation due to the heat. Also involved in this might be the effect of speed,



for the greater the amount that the oil was splashed around in the motor, the greater would be the evaporation rate and thus the greater would be the viscosity increase. No calculations with respect to the amount the viscosities in the motor were actually affected were done, due to an inability to accurately simulate outside the motor the evaporation occurring inside, hence only a conclusion on a relative basis was drawn. Tied in with this volatility was the flash point of the new oils. (Appendix V) That is, if listed in order of increasing flash point they are found to be Z 5W-30, X 5W-30, and Y 5W-30, which corresponds to the decreasing evaporation rate and the decreasing presence of the upturn of the viscosity curves.

#### 6.4 Variability Within a Make and Grade of Oil

Referring to runs one and two quite different results were found. The oil used for these runs was the same make and grade as that used for runs 6 through 19, the only difference being the source of purchase. In each of runs one and two, the percentage viscosity drop was greater than that for the corresponding runs at the same speed using the other oil, with no increase whatsoever being noticed, even at 0 F. As concluded earlier the volatility of the base oil seemed to be the most important factor in determining the shape of the viscosity curve, with the flash point being very closely related to this property. Oil Xa 5W-30, which gave these different results, had a much higher flash point than did any of the other three SAE 5W-30 oils used, thus again reinforcing the evidence already observed. When insolubles were considered run two had the highest value as compared to the other 1500 rpm runs using oil X 5W-30. If insolubles were important in the viscosity increases found, run two would have had the highest increase, or at least would have had a comparable





upswing to the curve, if not a greater one, however this did not occur. This result further eliminates the effect of insolubles and substantiates the results described in section 6.3.2. Oxidation products for runs 1,2, 10, and 14 were approximately equal, thus their effects should have caused no difference among the runs. Run two had a lower dilution value than the other comparable runs, hence a higher viscosity should be recorded, but was not. Thus a great variability within a single make and grade was found to exist, further complicating a comparison among makes.

#### 6.5 Other Effects on Viscosity Change

Throughout the series of runs using the three makes of oils the same trend, with respect to upswing, was found, that is the least was observed with oil Y, the most with oil Z, regardless of the grade used (figures 21 and 22). As mentioned for the SAE 5W-30 oils, the temperature of viscosity measurement had a pronounced effect on this upswing. That was the lower the temperature, the greater were the effects, regardless of the grade of oil being considered (figures 21 and 22).

As was found by Preuss et al (29), the author noted that the greater the initial viscosity of the multigraded oil, the greater was the viscosity drop. The reason for this being that for the same rates of shear, that is speed, higher viscosity produces a higher shear stress, and hence a greater polymer breakdown.

An interesting side issue was brought out by runs 23, 26, and 28 run in the flathead Ford using oil Y 5W-30. Instead of slight differences occurring with respect to load effects and sampling effects, relatively large effects were found. Also the minimum sampling run



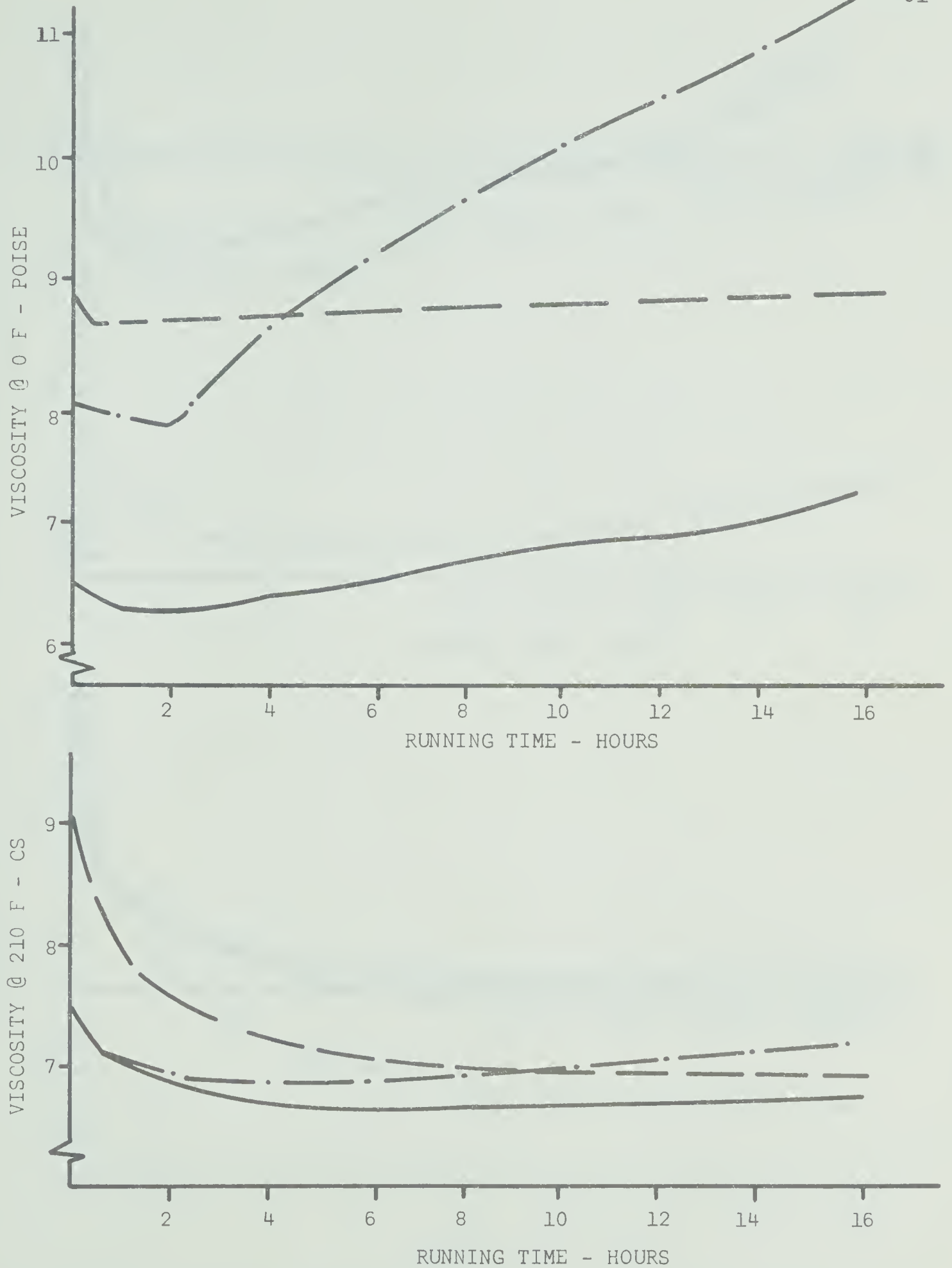


Figure 21: Viscosity comparison (0 F and 210 F) of three SAE 5W-20 oils run at 3000 rpm.



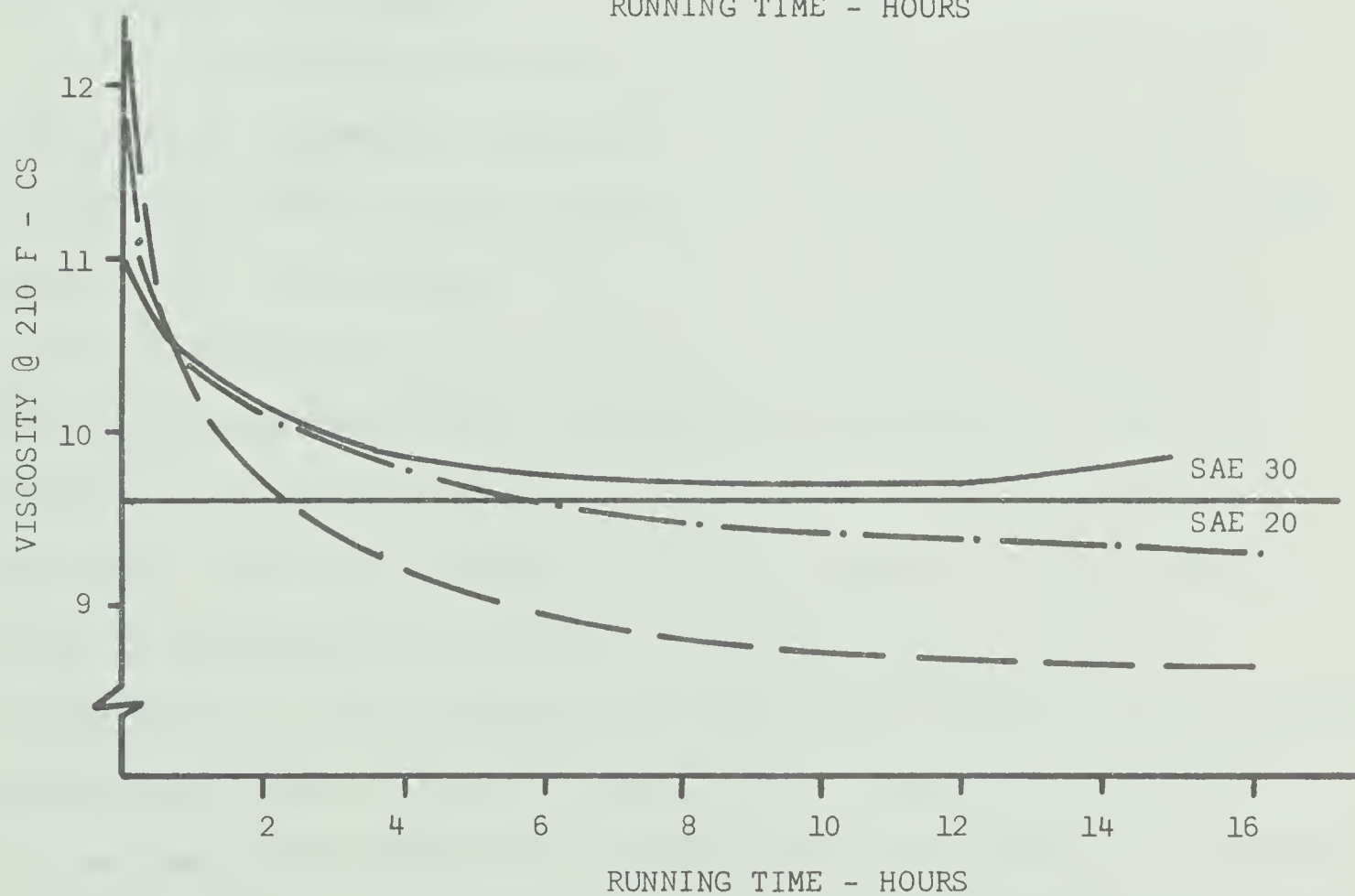
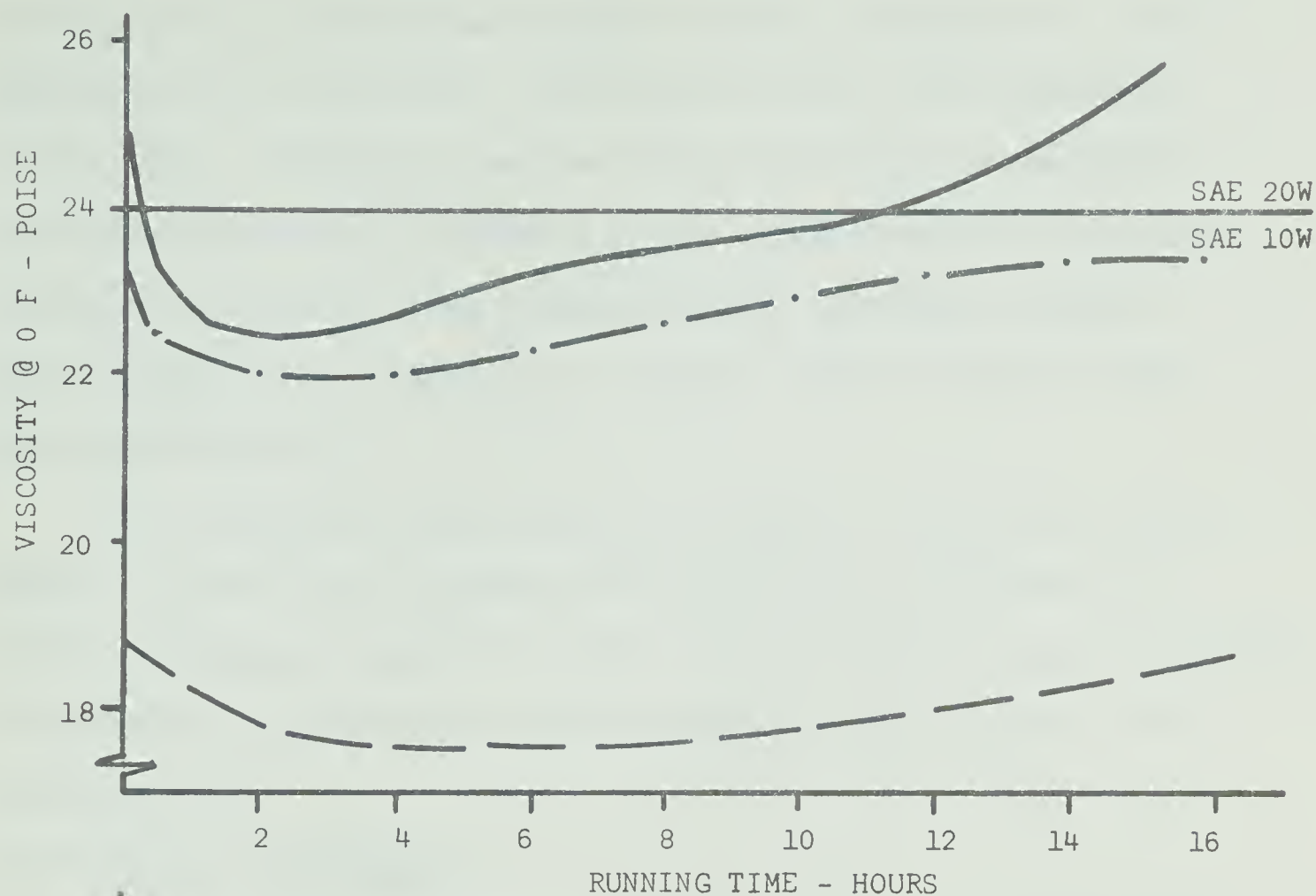


Figure 22: Viscosity comparison (0 F and 210 F) of three SAE 10W-30 oils run at 3000 rpm.



values were below the maximum sampling run which was opposite to that observed for the X 5W-30 oil. The reason for this can be explained fairly simply. During the last few runs of this motor, a connecting rod bearing was failing, causing a greater shear stress to be produced as each run progressed, thus producing greater viscosity loss than would be expected and therefore the departure from the results found for the X 5W-30 oil.

Water contamination was checked for several of the runs, but was found to be less than 0.2 percent thus this was not considered as a factor influencing viscosities found. Since the results proved unimportant no appendix was given in this thesis showing the water content of the crankcase oils.

#### 6.6 Changes in SAE Grades

All of the SAE 5W-30 and SAE 10W-30 oils, and the SAE 10W-40 oil had their viscosities decreased by such an amount so as to become a grade lower, at 210 F, after running in the 292 Ford at either 1500 rpm or 3000 rpm. In the flathead Ford, the Y 5W-30 oil sheared below the SAE 30 classification at both 1500 rpm and 3000 rpm whereas the X 5W-30 oil only sheared below this classification for the 1500 rpm run. The X 10W-30 oil sheared to an SAE 20W oil for both the 1500 rpm and 2250 rpm runs. Thus there is a great variability between motor types and oil makes in bringing about a decrease in SAE grade during service. If viscosities at 0 F are considered the results show that oil X 10W-30 became an SAE 20W-30 after 11 hours of running at 3000 rpm in the flathead Ford. In the case of the Z 5W-30 oil in either motor the oil viscosity increased from an SAE 5W to an SAE 10W after 8 to 11 hours of running depending on the motor. Other than these three instances no other oils had their





viscosities increased so as to become a grade heavier at 0 F. These two effects show the disadvantages of multigrade oils, for if there is a decrease in SAE grade (at 210 F), adequate lubrication for the motor during operation is not provided. On the other hand an increase in SAE grade, (at 0 F), in fact any increase in viscosity, will reduce starting ability.

#### 6.7 Effects of Motor on Viscosity Change

The motor greatly affects viscosity change, for in all cases the 292 Ford caused a greater viscosity breakdown and less of an increase than did the flathead Ford when the same oil and speed conditions were maintained (figures 17, 18, 21, and 22).

Agreeing with the findings of Courtney and Roscoe (5), figure 23 shows that the same motor does not produce the same viscosity change in an oil even though operating conditions, that is speed, load, and oil make and grade, are identical. As mileage on the motor increases viscosity breakdown becomes less, this probably being due to the wearing away of the sharp edges present in a new or rebuilt motor. At 210 F there was a difference of 0.5 cs at the end of the runs, with the newer motor condition producing the greatest viscosity breakdown. At 0 F the oils ended up at essentially the same value and varied throughout the length of the run by only 0.2 poise.

Thus this difference would indicate that an oil run at the beginning of the tests cannot really be compared with a run at the end due to the variability of the motor.

Two methods to compensate for this variability would be:

- 1) establish a calibration curve for the motor by using one oil in a series of consecutive runs, after which the motor is rebuilt. This series of runs would give the relationship between motor changes and viscosity



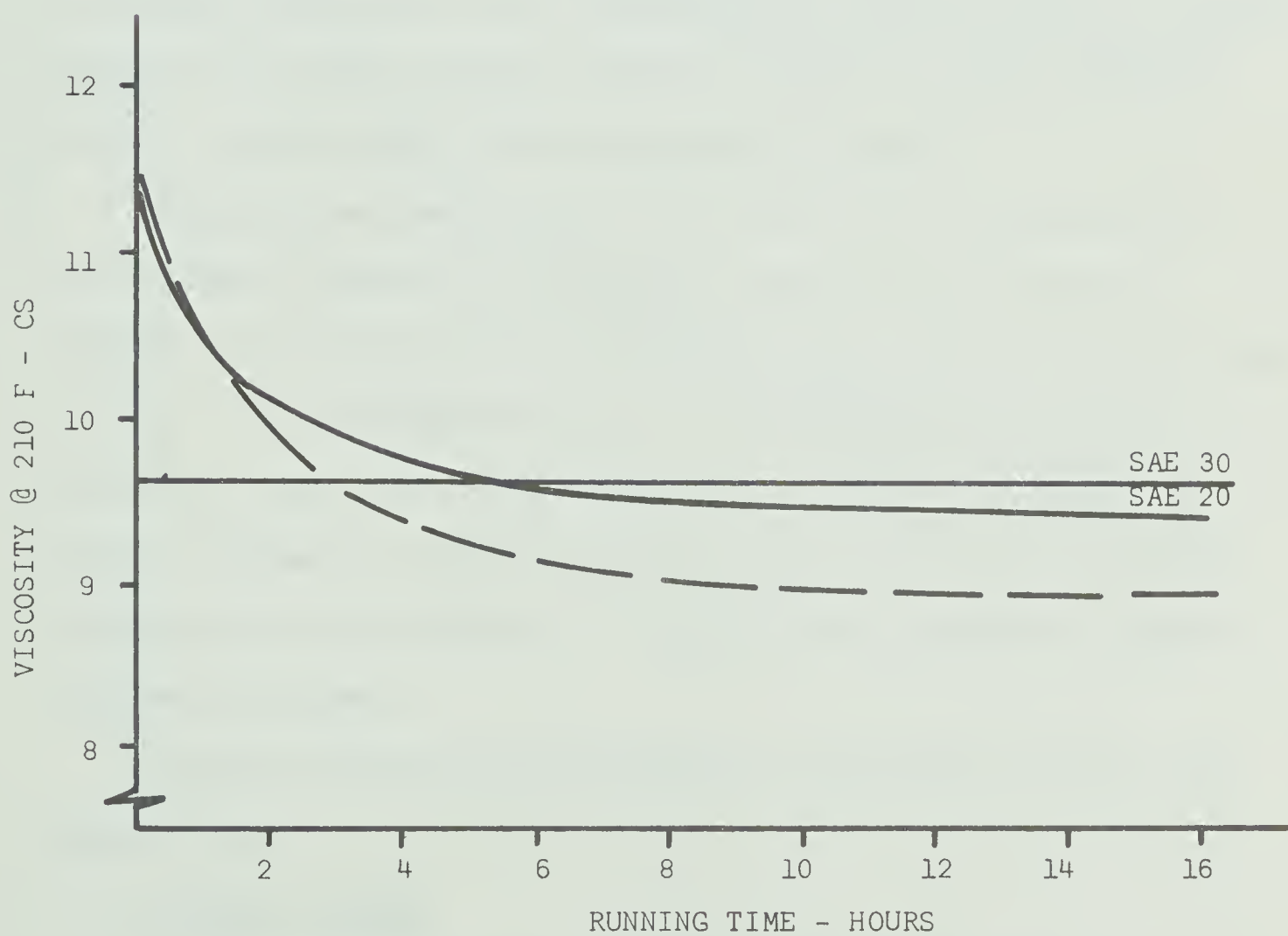
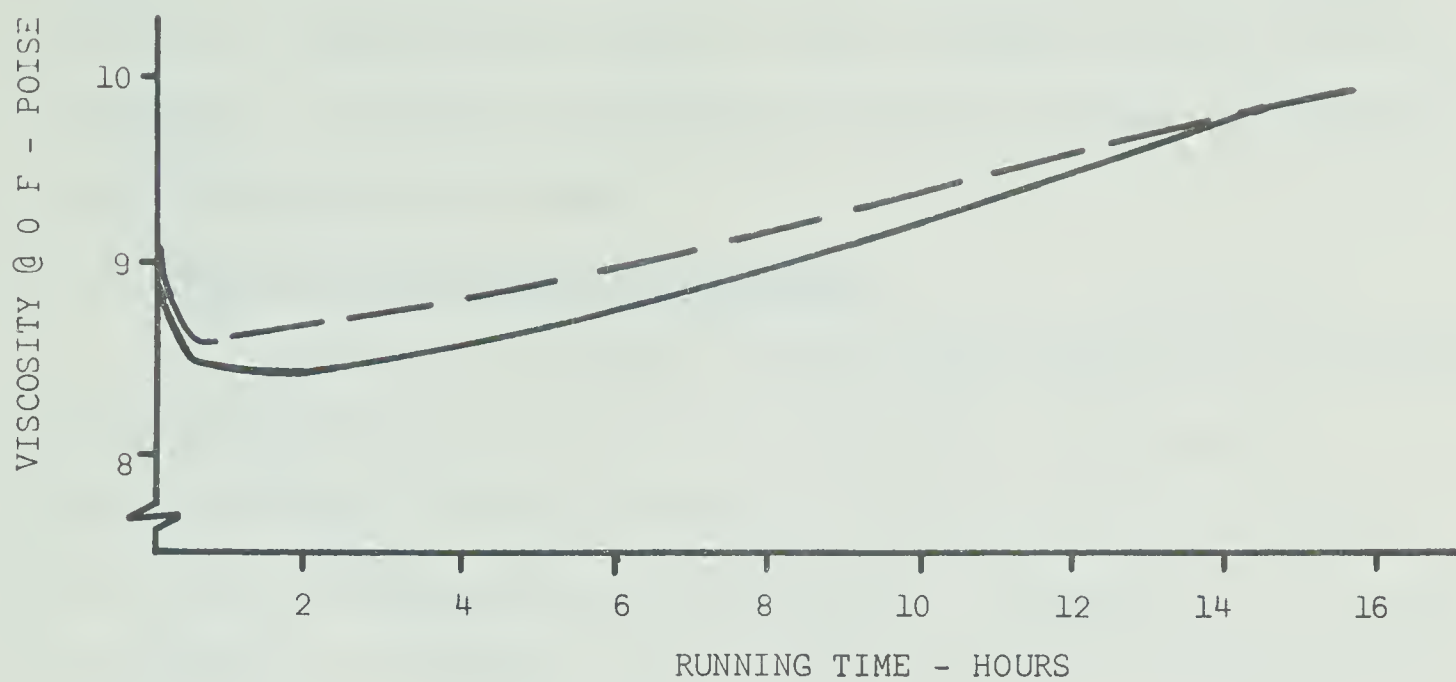


Figure 23: The effect of motor condition on viscosity (0 F and 210 F) for the X 5W-30 oil run at 3000 rpm.



changes, thus allowing the researcher to compensate for the changing motor when conducting test runs; 2) use a standard oil every three to four runs, thus giving an indication of the motor changes and allowing for a compensation to be made.

#### 6.8 Percentage Comparison of Viscosities

Figures 24 to 29 give the percentage comparisons for SAE 5W-30, SAE 10W-30, and SAE 5W-20 oils at 0 F and 210 F. For the 210 F temperatures the greatest percentages of viscosity loss were found in oil Y, for the reasons given in section 6.5. A comparison in the amount of increase or decrease in viscosity among oil makes can be appreciated only in these percentage curves, because all start at 100 percent, with the slopes of the curves then indicating the relative viscosity changes. The SAE 30 oil was included in figures 24 and 25 to allow comparison between a straight grade and a multigraded 30 weight.

Viscosity decreases in SAE 5W-30 oils at 210 F varied from 10 to 36 percent, whereas at 0 F decreases ranged from 20 percent to negative 48 percent (increase), depending on the speed of operation and oil type. For the SAE 5W-20 oils at 210 F decreases varied from 7 to 26 percent, while at 0 F they varied from 4 percent to negative 43 percent (increase). SAE 10W-30 oils at 210 F had decreases ranging from 13 to 30 percent while at 0 F ranged from 11 percent to negative 2 percent (increase).

The above shows the great variability among makes for the same grade of oil.

#### 6.9 Viscosity Indices

Figures 30 and 31, in conjunction with Appendix VI, give results of  $VI_e$  calculations. In all cases except for runs 2,5,10,22



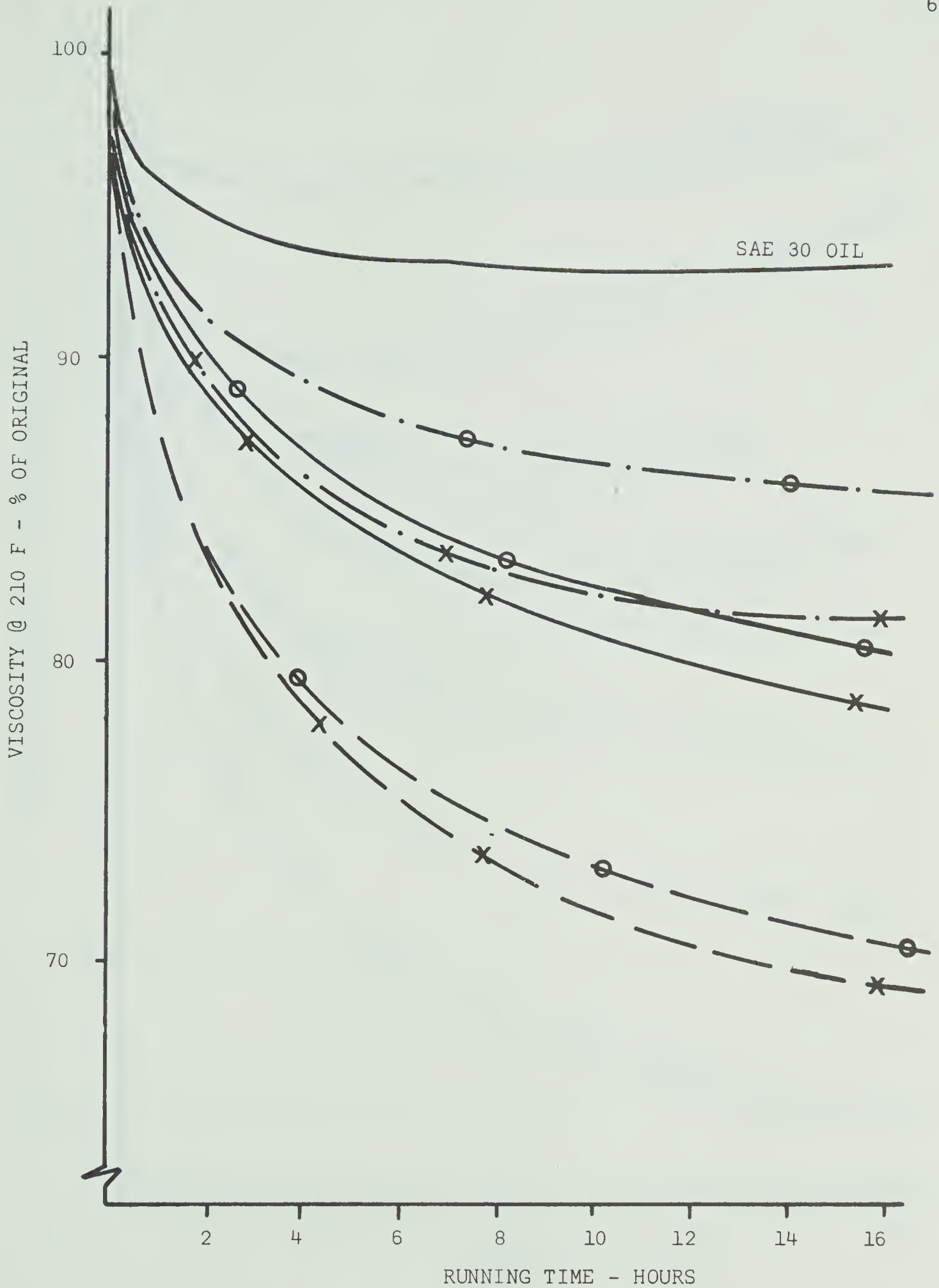


Figure 24: Percentage viscosity comparison (210 F) of three SAE 5W-30 oils run at 1500 rpm.





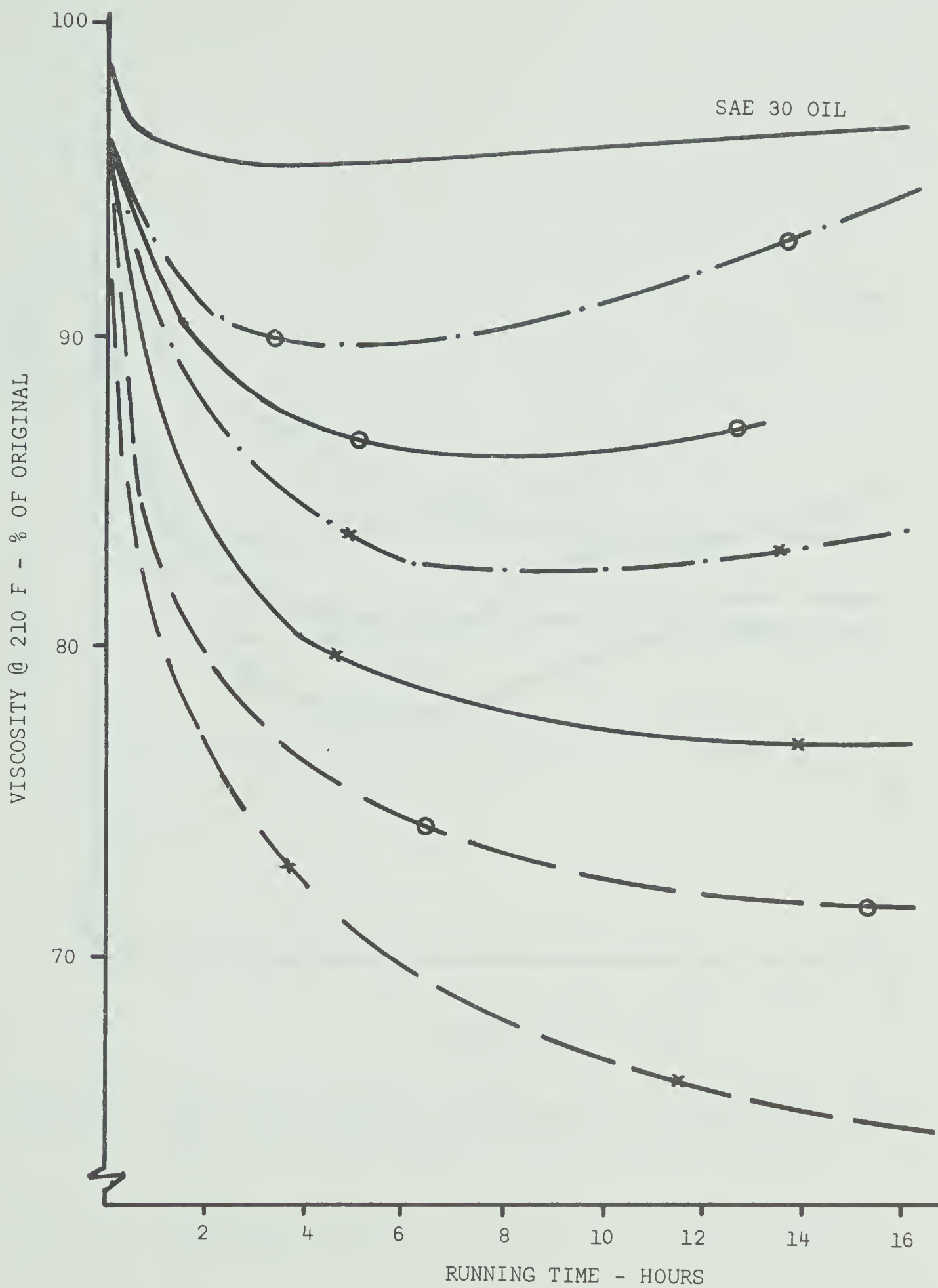


Figure 25: Percentage viscosity comparison (210 F) of three SAE 5W-30 oils run at 3000 rpm.



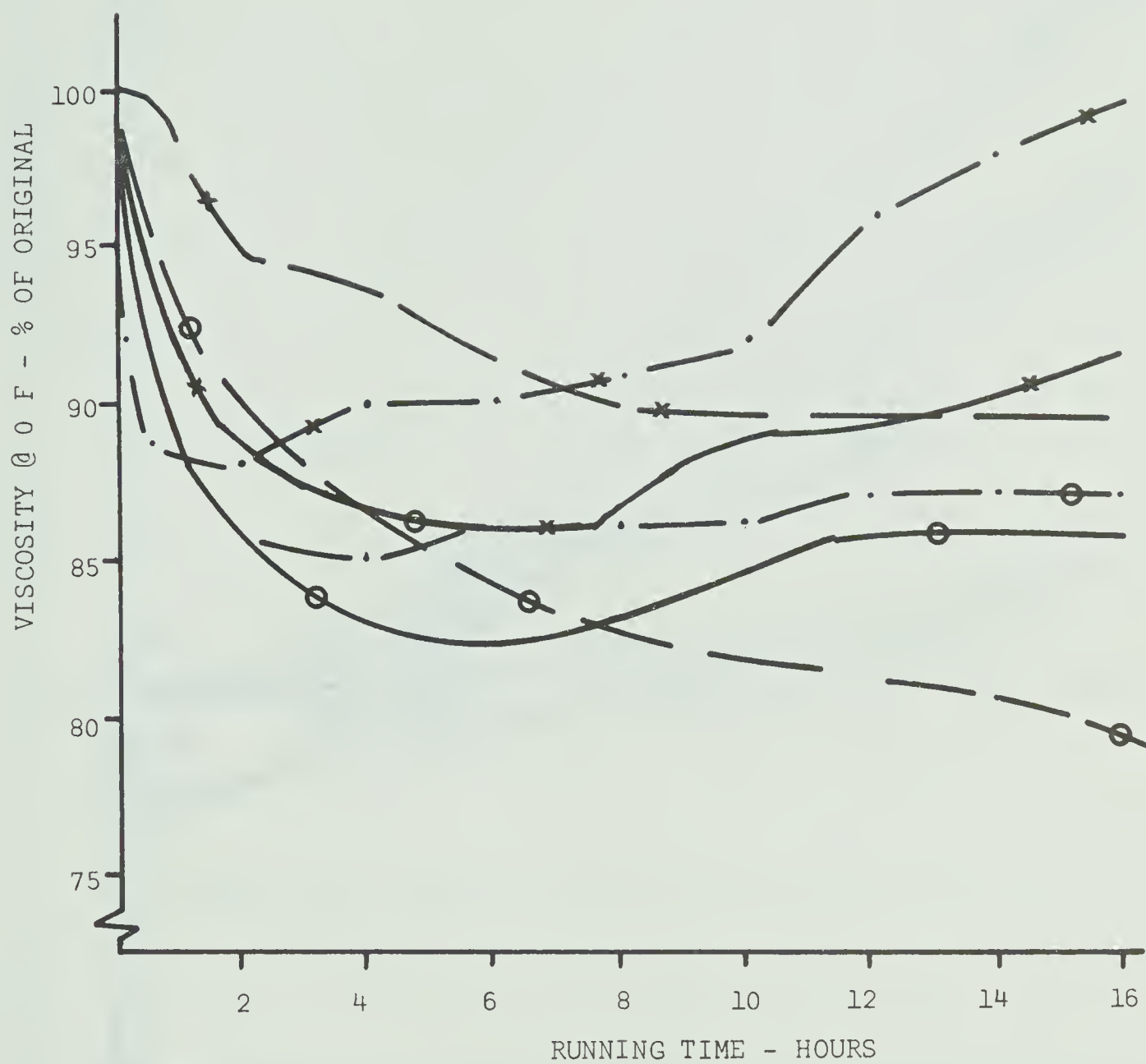


Figure 26: Percentage viscosity comparison (0 F) of three SAE 5W-30 oils run at 1500 rpm.



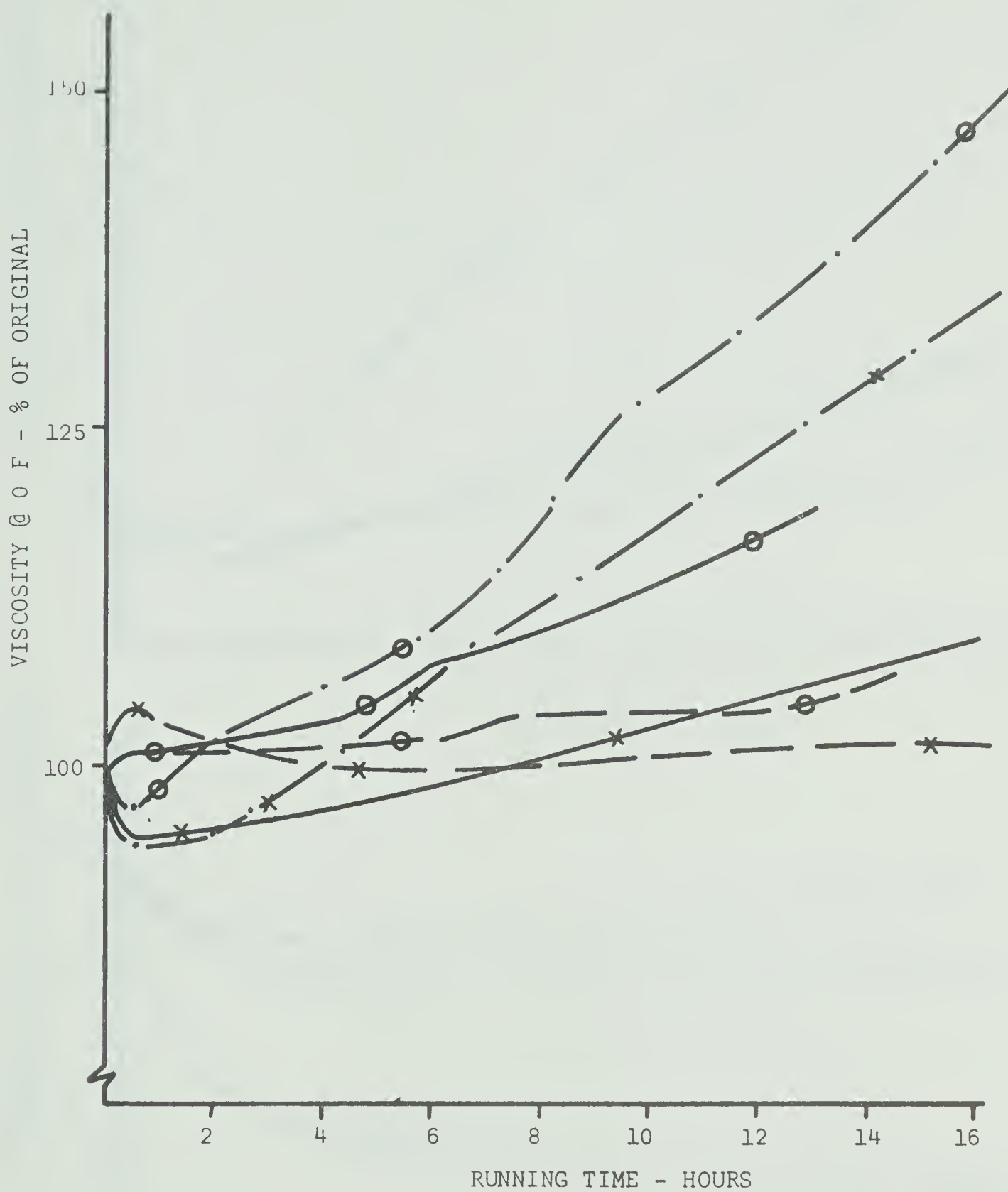


Figure 27: Percentage viscosity comparison (0 F) of three SAE 5W-30 oils run at 3000 rpm.



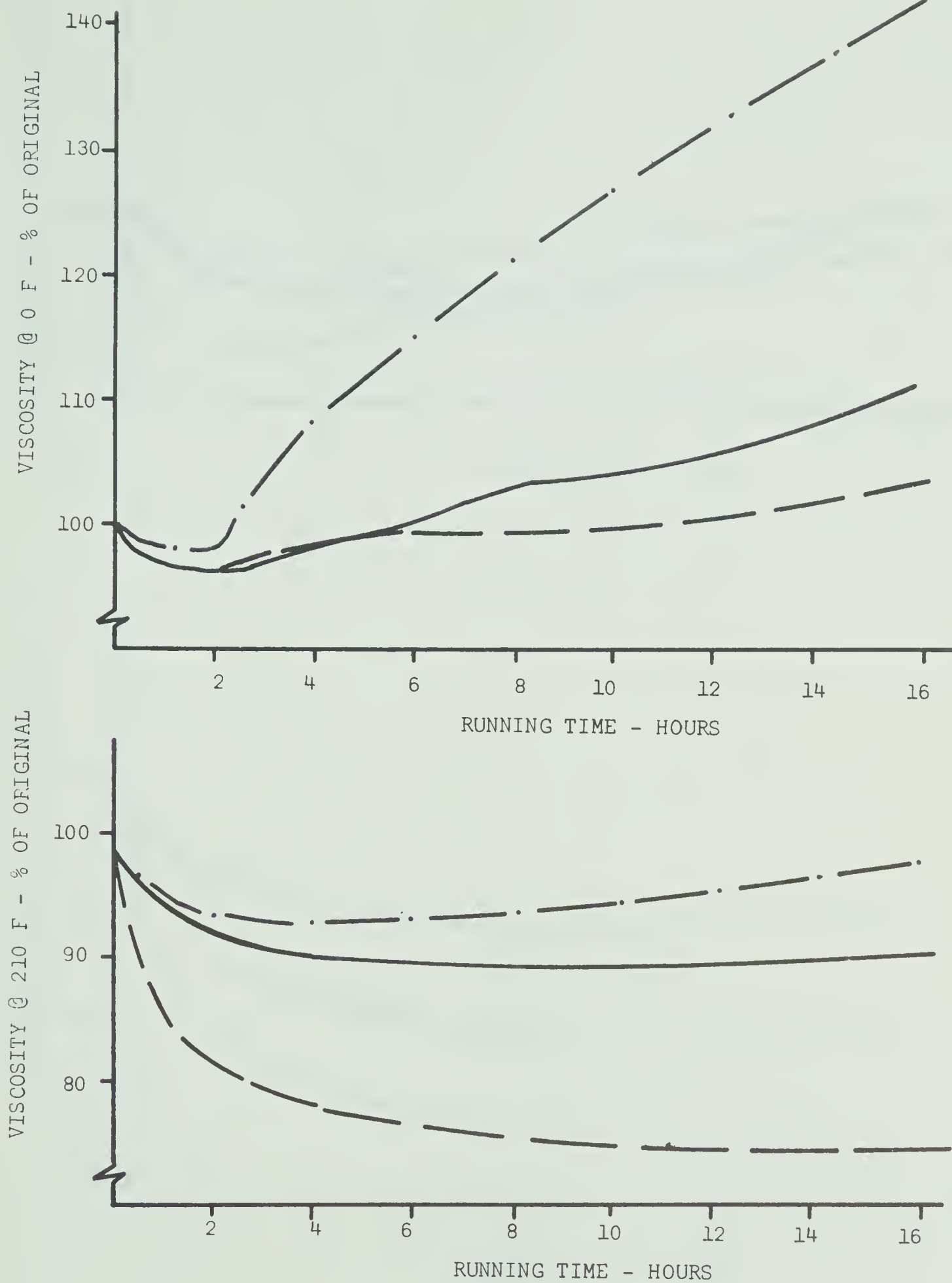


Figure 28: Percentage viscosity comparison (0 F and 210 F) of three SAE 5W-20 oils run at 3000 rpm.





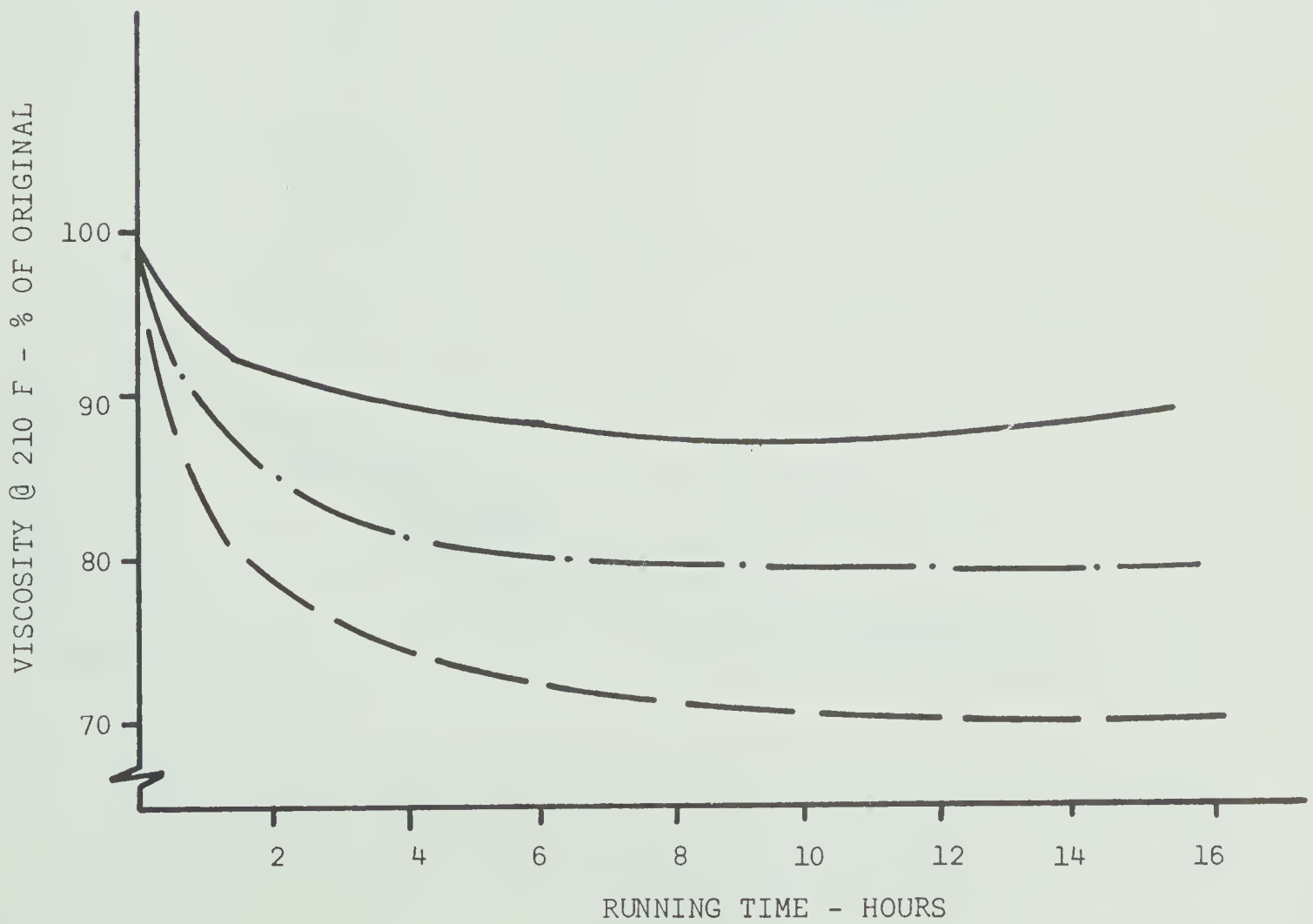
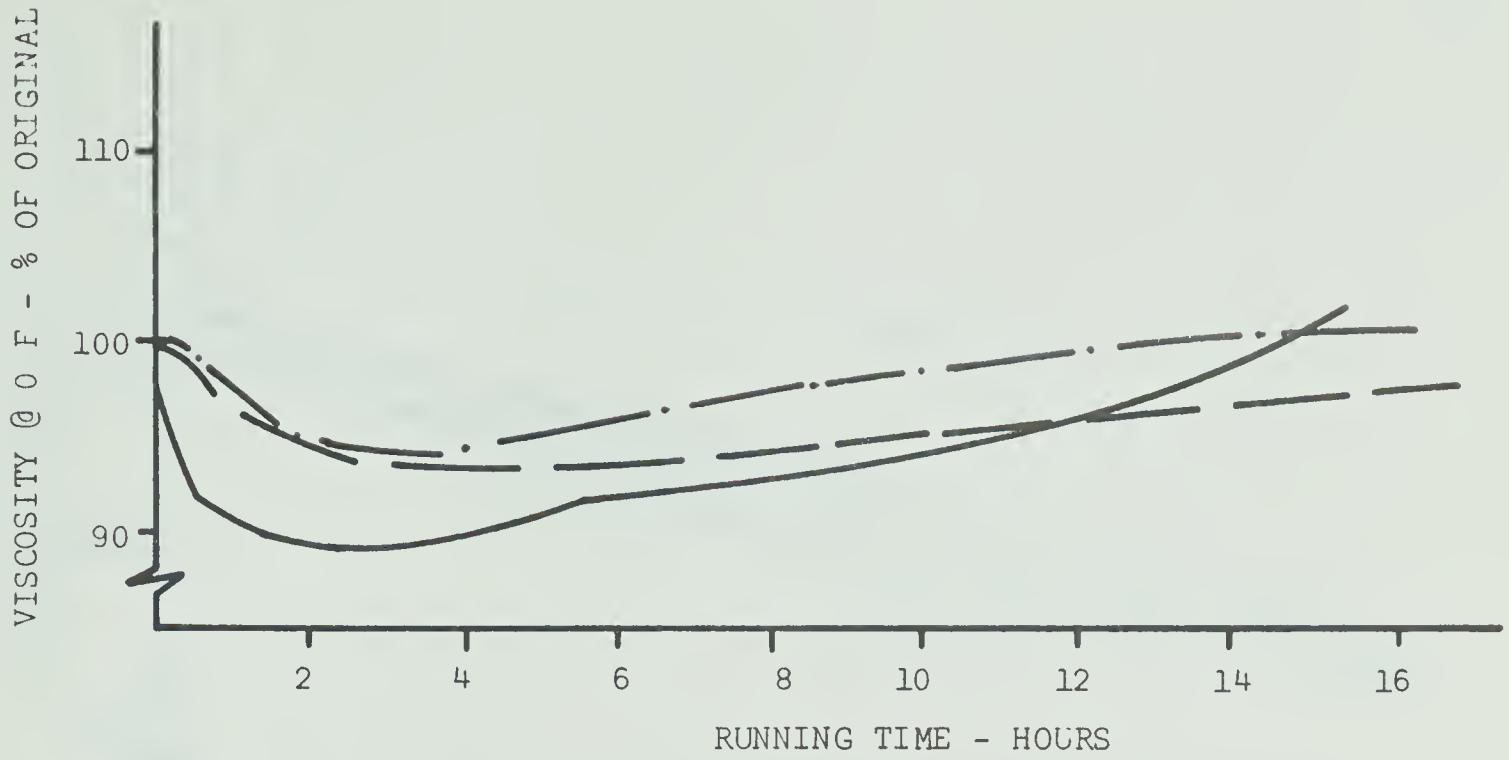


Figure 29: Percentage viscosity comparison (0 F and 210 F) of three SAE 10W-30 oils run at 3000 rpm.



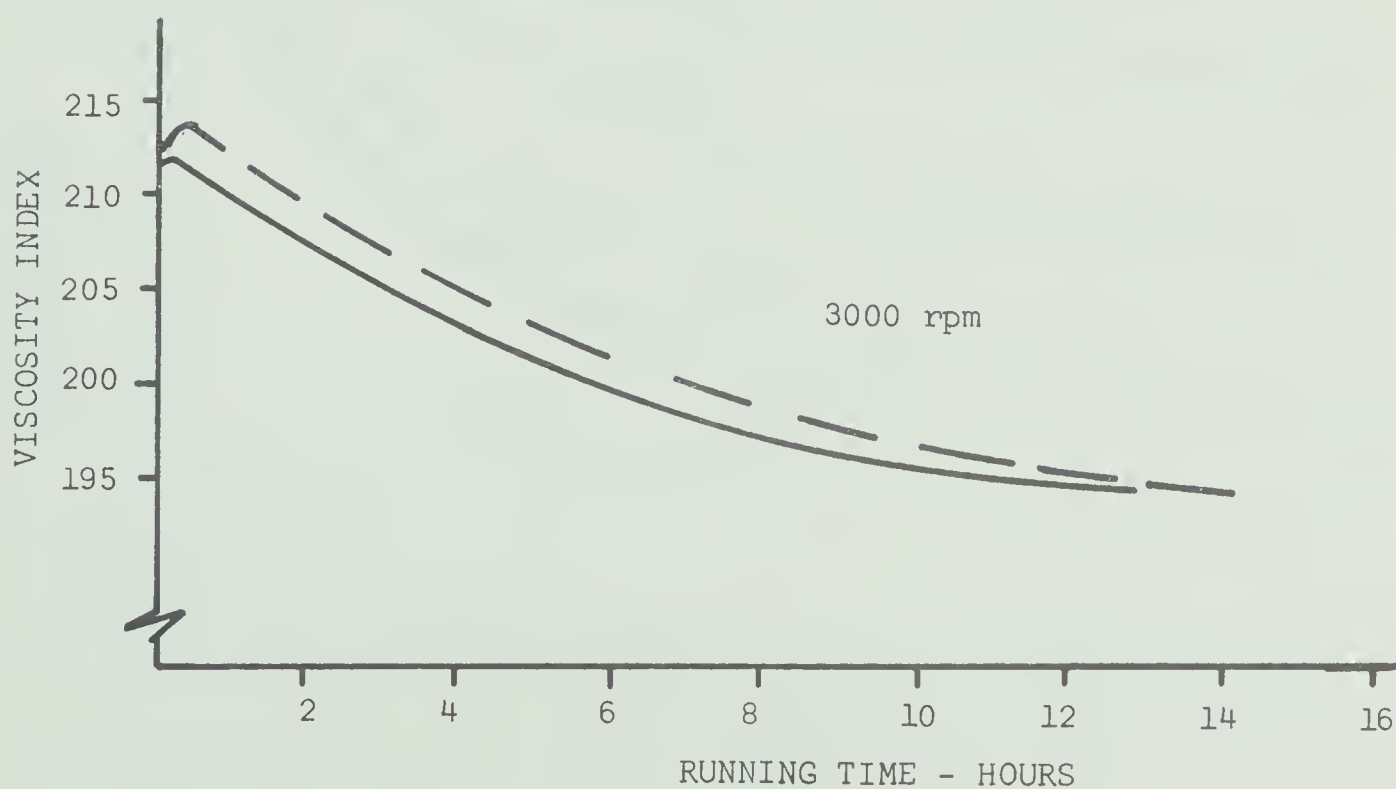
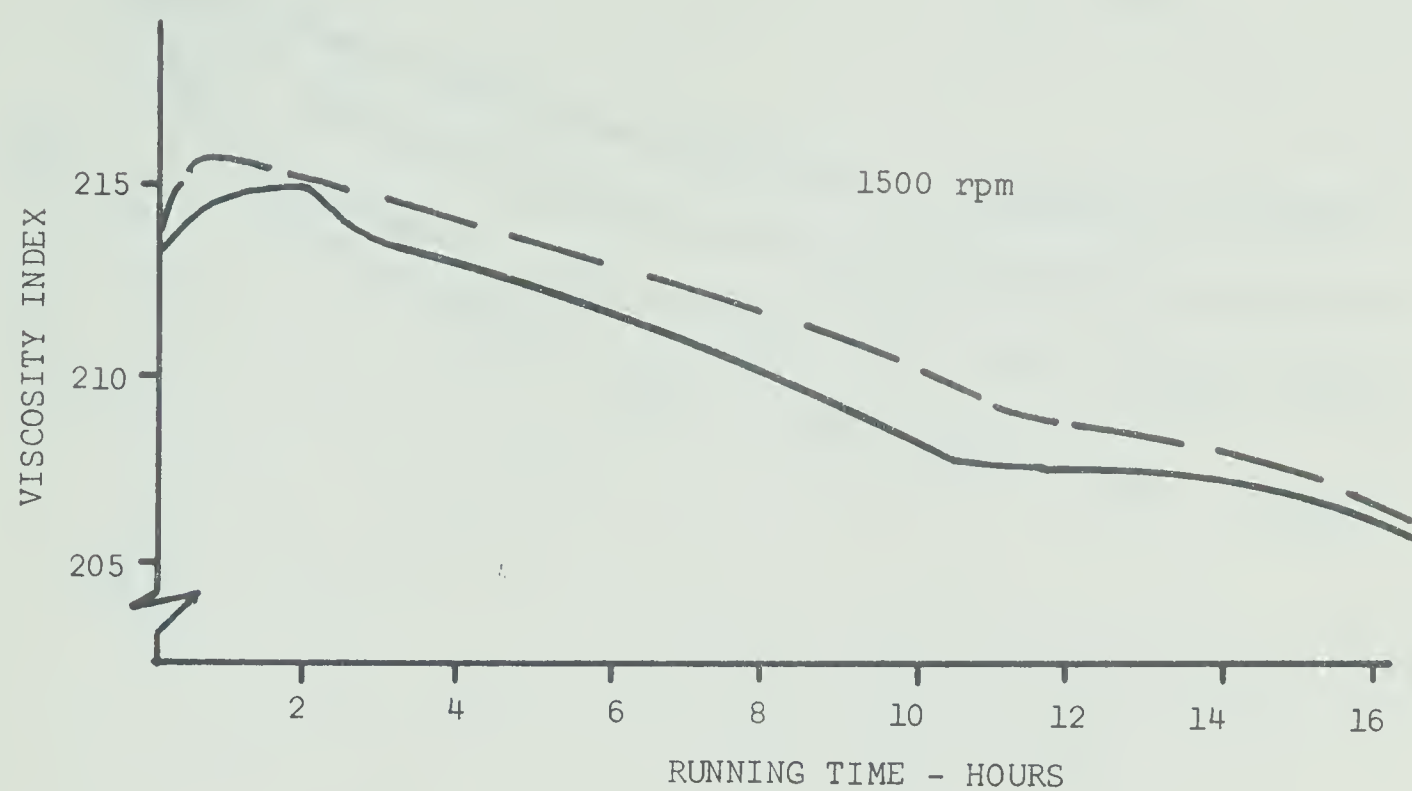


Figure 30: The effect of load on Viscosity Index extensions for 1500 rpm and 3000 rpm.



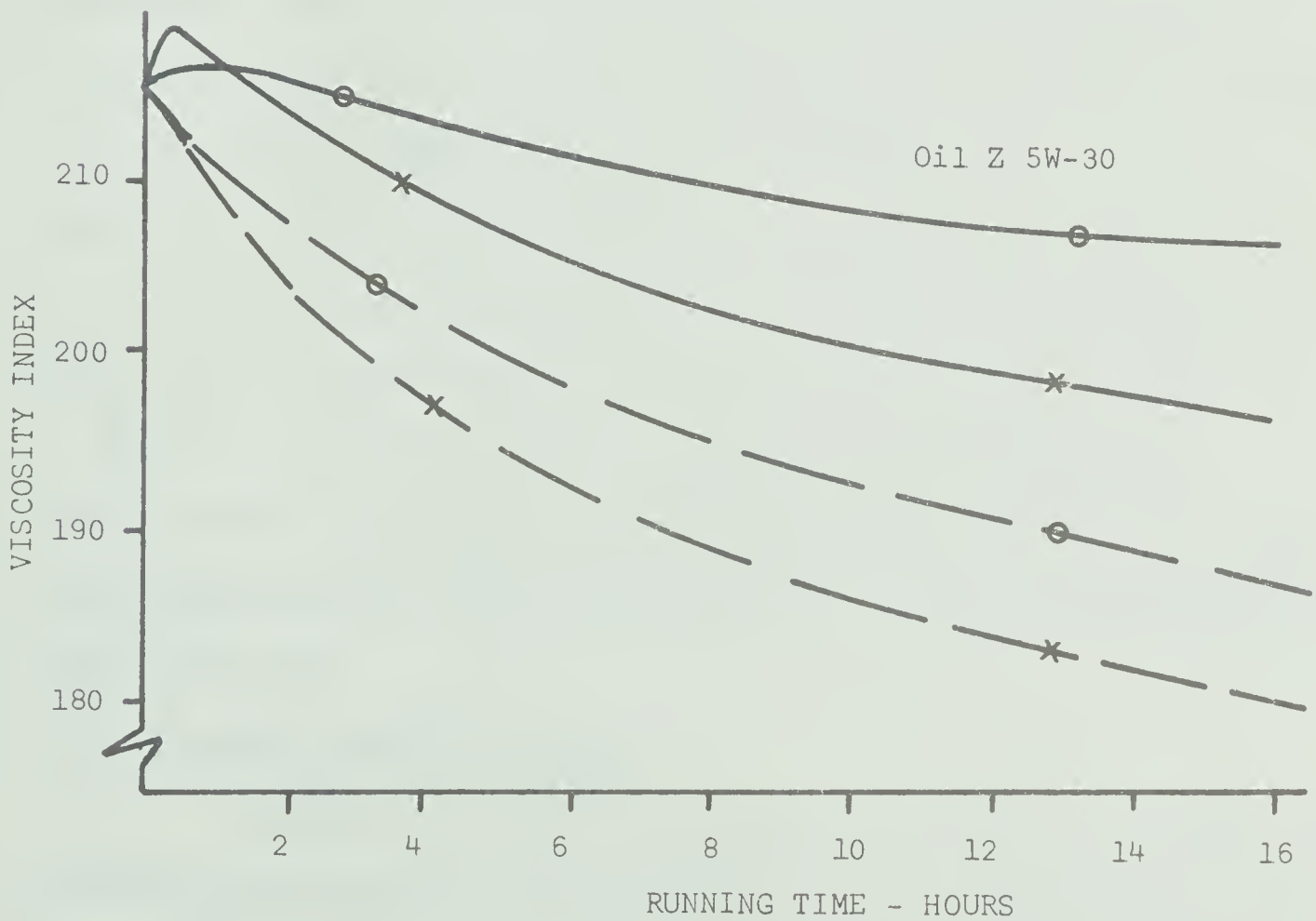
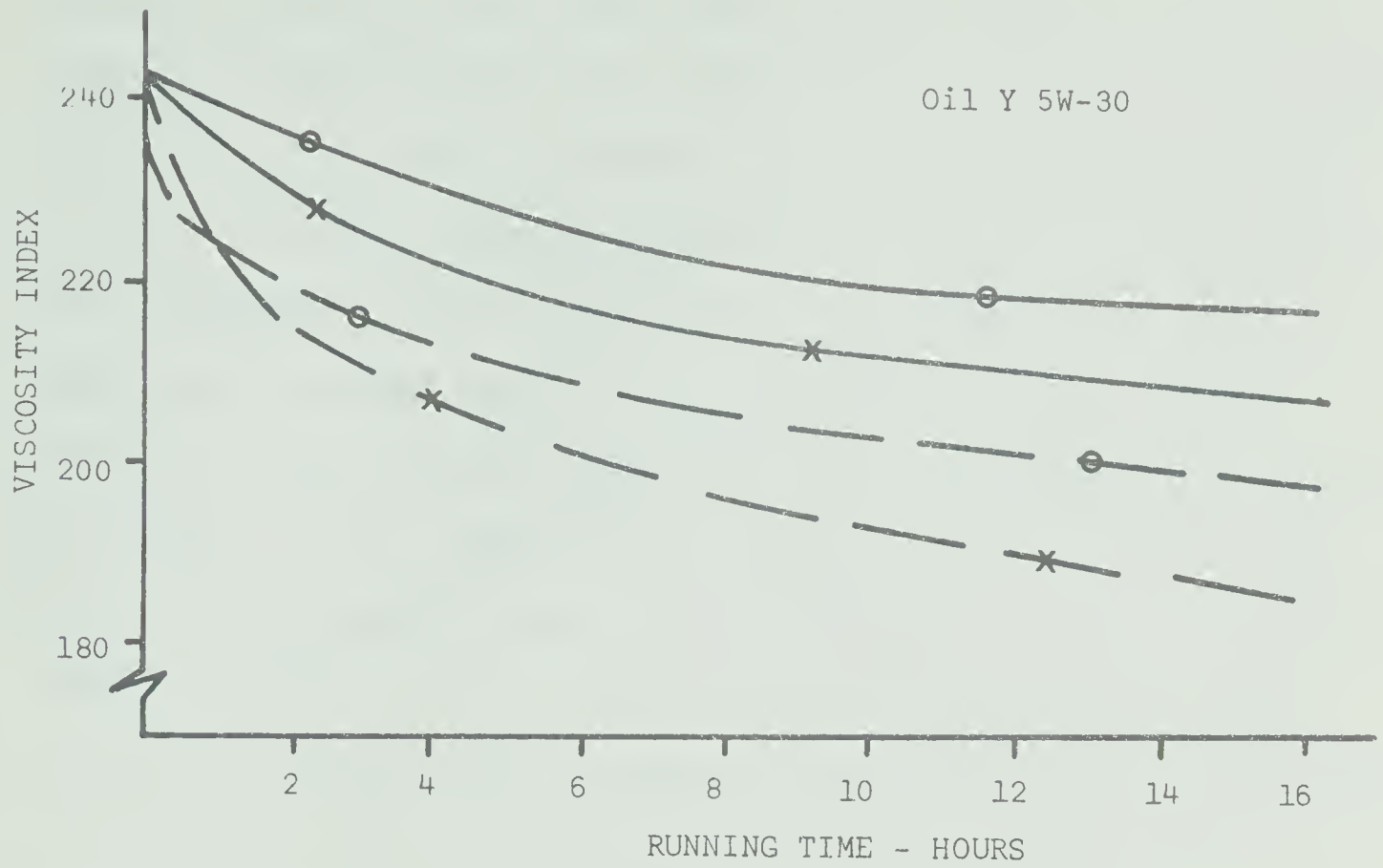


Figure 31: The effect of speed on Viscosity Index extensions for oils Y 5W-30 and Z 5W-30.



35, and 36, the  $VI_e$  either have a small increase initially and then decrease, or fall throughout the entire length of the run. In the case of runs 2, 5, 10 and 22, a possible reason for the odd results could be due to incorrect viscosity measurements. Since  $VI_e$  are calculated using logarithms of the two viscosities, one divided by the other, a small error in either could produce an error in the  $VI_e$ . Since the errors found are relatively small, this could quite feasibly account for the results. In the case of runs 35 and 36 there is an initial large increase in VI and then essentially a levelling off occurs, containing minor fluctuations. In the majority of cases concerning multigraded oils the results show that although the actual viscosities of the used oil increased, the  $VI_e$  decreased thus showing a continual shearing of the polymer. That is, the oil becomes more and more susceptible to viscosity changes with a change in temperature. In the case of the SAE 30 oil, since the amount of VI improver contained was minimal, an essentially constant VI was maintained. No satisfactory explanation was found for the initial increase in VI or  $VI_e$  but could possibly be tied in with the rate at which the viscosities at 100 F and 210 F fell in relation to each other and the logarithmic calculation of VI. Another possible explanation could be a temporary polymerization effect during the early part of the run when the new oil was first exposed to heated conditions.

#### 6.10 University Service Vehicles

Appendix VIII gives the results of the tests on X 10W-30 oils taken from the University service vehicles in which dilution was found to be less than two percent. Figure 32 shows the viscosities of the crankcase oils, at 0 F and 210 F, as decreasing initially followed by a





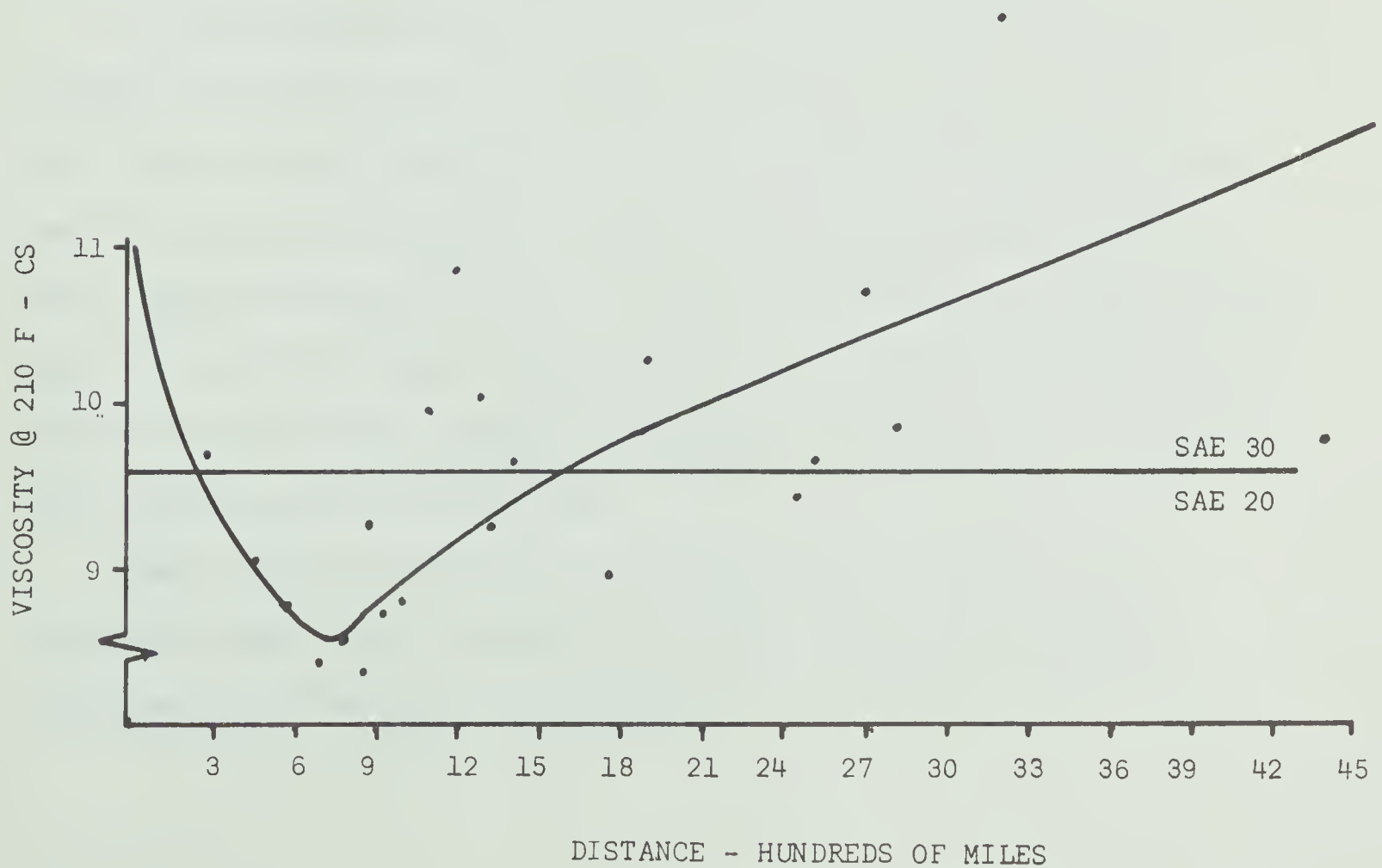
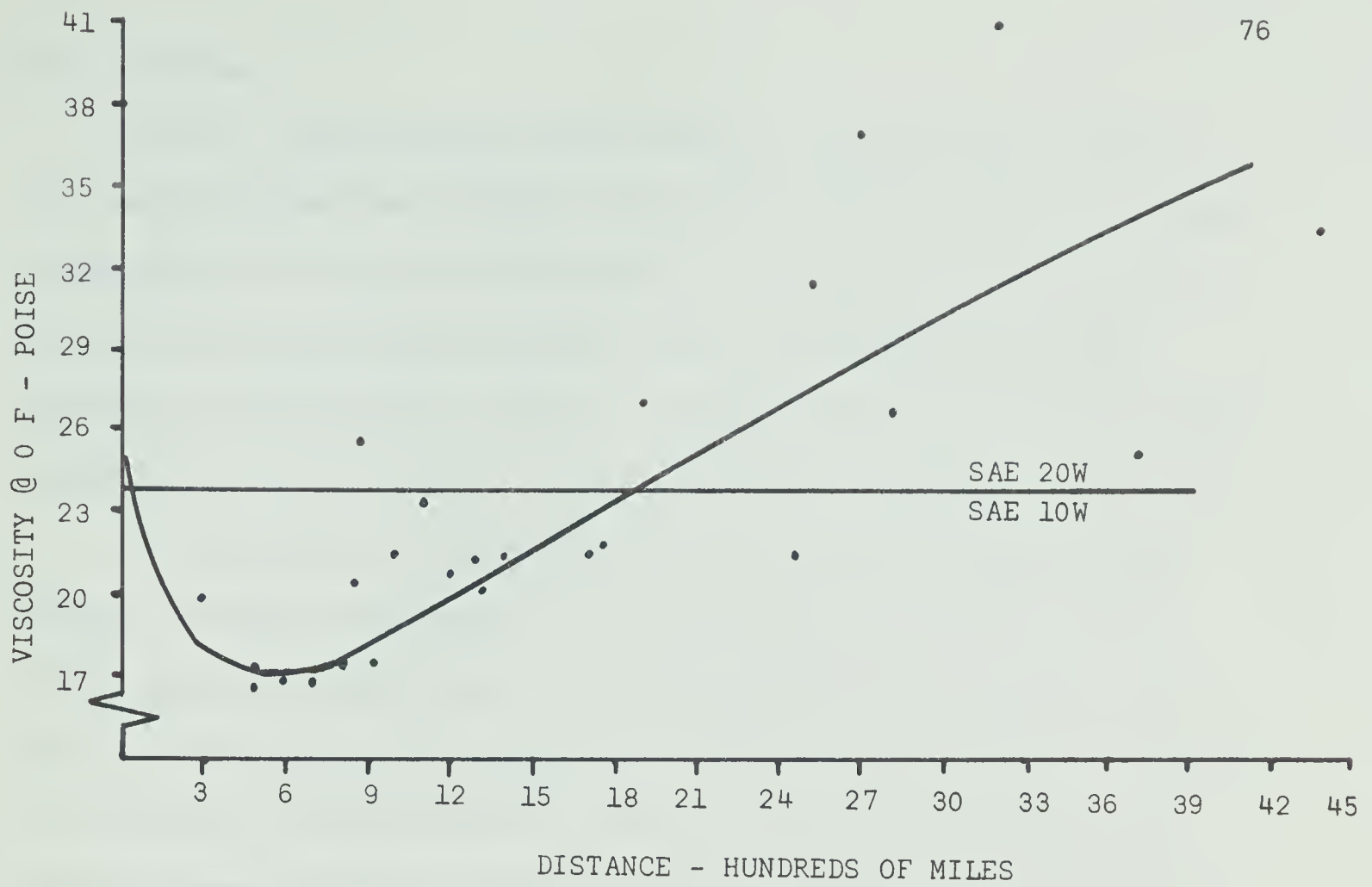


Figure 32: The effect of field conditions (University Service Vehicles) on viscosity (0 F and 210 F) for the X 10W-30 oil.



slow increase.

Clearly, a much greater drop occurred in actual service than in the laboratory and the increases came about much more slowly. In order to compare field data with laboratory data, recognition must be given to the differences between service vehicles and laboratory engines regarding miles covered. That is, 16 hours of running in the laboratory at 2250 rpm is only 720 miles whereas field data extends to 4200 miles.

In the case of the viscosities at 0 F in the laboratory minimum values occurred at six hours or 270 miles, whereas in field service these occurred in the range of 400 to 900 miles. The severity of the drop in field service was much greater, falling to 17 poise, as compared to 22 poise in the laboratory. However, in field service there were several cases in which the oil passed from the SAE 10W to the SAE 20W range, these generally occurring after 1800 miles of service.

In the laboratory viscosities at 210 F dropped from an SAE 30 to an SAE 20 after 12 hours or 540 miles, attaining a minimum value of 9.53 cs at 16 hours (720 miles). However, in field service between 500 and 1000 miles were required to reach minimum values, these being well into the SAE 20 range at 8.50 cs. After about 1500 miles of field service, generally all of the oils' viscosities had increased such that the SAE 30 classification had been regained even though no increase was observed in the laboratory tests for 2250 rpm.

These results indicate that laboratory tests represent actual service to some degree, although field tests show greater severity of increases and decreases in viscosity.



## 7. CONCLUSIONS

Conclusions drawn from this research work concerning viscosity changes in service were:

1. The study of motor oils in service is a very complex subject with many factors influencing the viscosities as measured, these being fuel dilution, oxidation products, insolubles, base oil volatility, and polymer degradation.
2. Base oil volatility was the most important factor tending to mask the polymer degradation or viscosity loss of the oils studied.
3. As the flash point of a particular grade of oil increased, the effect of base oil volatility decreased, that is, the highest flash point was associated with the oil that had the least amount of viscosity increase.
4. The effect of base oil volatility on viscosity measurement increased as the temperature decreased.
5. Crankcase dilution had a so-called "tolerance" level, beyond which the viscosity was greatly decreased by the addition of any more gasoline.
6. The effect of crankcase dilution on viscosity increased as the temperature of measurement decreased.
7. The higher the initial viscosity of the oil, the greater was the viscosity decrease on a numerical as well as a percentage basis.



8. The effects of load on viscosity changes were small, and could be safely neglected.
9. The effects of speed on viscosity change, whether increase or decrease were great. This was due to one or both of two factors: 1) greater mechanical speed, hence a greater shear stress produced and a greater "splashing" effect of the oil causing greater evaporation of the light ends of the base oil, and 2) higher operating temperatures thus producing greater evaporation.
10. Removal of oil during a run, thereby decreasing the amount in the motor, had no appreciable effect on the viscosity change curve.
11. Different motors brought about vastly different viscosity changes in the same oil when run at the same speed.
12. As the motor ran, or as miles were accumulated, there was a decreasing tendency to shear the oil, thus producing less of a viscosity loss.
13. Different makes of the same grade of oil varied greatly in their viscosity change curves, some increasing an SAE grade at 0 F, others decreasing an SAE grade at 210 F.
14. Each individual oil company had a characteristic curve associated with its product. That is, either an increase at 0 F or a decrease at 210 F occurred after running, regardless of the grade. This likely being due to the





different base oil stocks used.

15. Machines used to predict the shear stability of motor oils give only one aspect of the viscosity changes (polymer degradation) brought about in an operating motor but do not at present simulate any of the other factors that can cause viscosity changes.
16. Laboratory motors can be used to represent field service but carefully-controlled field runs must be associated with laboratory tests to substantiate laboratory work.



## 8. RECOMMENDATIONS FOR FURTHER WORK

As a result of the data collected from this series of experiments there were several suggestions made in regards to obtaining more meaningful data.

1. The motor should have a so-called calibration curve drawn up. This would consist of, say, 50 runs of some standard oil run in succession at alternating speeds, thus enabling the researcher to determine the exact effects of motor change on viscosity degradation. The motor would then be rebuilt and the test oils could be run. The alternative to this would be to run the standard oil every three or four runs, again allowing the researcher to take into account motor changes.
2. More extensive and carefully controlled dilution tests and base oil volatility tests should be conducted on all of the oils used for a series of runs. For the dilution tests more samples should be made allowing the plotting of a more accurate curve. In the case of volatility studies temperatures should be maintained at more constant levels and for longer periods of time.
3. Crankcase dilution should be distilled off under an inert gas atmosphere so that true viscosity of the oil could be measured.
4. Gas chromatography should be employed to determine whether a loss of the light ends of the oils or a polymerization effect occurs in the oils through usage.



5. The collection of actual field data should be better controlled to allow formulation of more valid comparisons with laboratory tests. That is, the oil added during service must be of the same make and grade as was originally placed in the motor thus eliminating erroneous results.



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## 10. APPENDICES



## APPENDIX I: REGULAR GRADE GASOLINE ANALYSIS

## Report of Analysis Motor Gasoline

Detail of Analysis by Alberta Government Specification, Regular Grade.

Summer Grades apply May 1 to Sept. 30, Winter Grades Nov. 1 to Mar. 31.

Values marked "Fail" do not comply with specifications.

Test	Specification	Sample Result
Appearance	Clear	Clear
Colour		Purple
Freezing Point °F	Max. -60	Pass
Distillation Range - % Fuel Evaporated - °F*		
10%	Min. 110    Max. 135	125
50%	Max. 245	197
90%	Max. 365	302
Reid Vapour Pressure, PSI	Max. 11	9.4
Lead Content gm/IG	Max. 5.05	1.26
Octane Rating (Research)	Min. 89	93.2
Sulfur %	Max. 0.15	0.05
Gum, Existent MG/100 ML	Max. 7	0.2
Corrosion	Max. 1	1B
Octane Rating (Motor)		82.9

\* Distillation results corrected to 29.92" Hg.



## APPENDIX II: 80-87 FUEL ANALYSIS

## Report of Analysis Motor Gasoline

Detail of Analysis by Alberta Government Specification, Regular Grade.  
 Summer Grades apply May 1 to Sept. 30, Winter Grades Nov. 1 to Mar. 31.  
 Values marked "Fail" do not comply with specifications

Test	Specifications	Sample Result
Appearance	Clear	Clear
Colour		Red
Freezing point °F	Max. -60	Pass
Distillation Range - % Fuel Evaporated - °F*		
10%	Min. 110 Max 135	147
50%	Max. 245	207
90%	Max. 365	238
Reid Vapour Pressure, PSI	Max. 11	6.0
Lead Content gm/IG	Max. 5.05	0.70
Octane Rating (Research)	Min.	86.9
Sulphur %	Max. 0.15	0.03
Gum, Existent MG/100 ML	Max. 7	0.0
Corrosion	Max. 1	1A
Octane Rating (Motor)		87.2

\* Distillation results corrected to 29.92" Hg.



APPENDIX III: TEST RUN DETAILS

Run No.	Motor †	Speed rpm	Oil	Load	½	1	1½	2	3	4	6	8	10	12	13	14	15	16	19	24	30
1	F	1500	Xa 5W-30		x	x	x	x	x	x	x	x	x	x	x	x		x			
2	F	1500	Xa 5W-30		x	x	x	x	x	x	x	x	x	x	x		x		x	x	x
3	F	2250	X 10W-30		x	x	x	x	x	x	x	x	x	x	x			x			
4	F	3000	X 10W-30		x	x	x	x	x	x	x	x	x	x	x		x				
5	F	1500	X 10W-30		x	x	x	x	x	x	x	x	x	x	x	x		x			
6	F	2250	X 5W-30		x	x	x	x	x	x	x	x	x	x	x	x		x			
7	F	3000	X 5W-30		x	x	x	x	x	x	x	x	x	x	x	x					
8	F	2250	X 5W-30																x		
9	F	3000	X 5W-30																x		
10	F	1500	X 5W-30		x	x	x	x	x	x	x	x	x	x	x	x		x			
11	F	2250	X 5W-30	x	x	x		x	x	x	x	x	x	x	x	x		x			
12	F	1500	X 5W-30	x	x	x		x	x	x	x	x	x	x	x	x		x			
13	F	3000	X 5W-30	x	x	x		x	x	x	x	x	x	x	x	x					
14	F	1500	X 5W-30															x			
15	F	2250	X 5W-30	x														x			
16	F	1500	X 5W-30	x														x			
17	F	3000	X 5W-30	x														x			
18*	F	3000	X 5W-30		x	x		x	x	x	x	x	x	x	x			x			
19*	F	3000	X 5W-30		x			x	x	x	x	x	x	x	x			x			
20	F	3000	Z 5W-30		x			x	x	x	x	x	x	x	x			x			
21	F	2250	Z 5W-30		x			x	x	x	x	x	x	x	x	x					





## APPENDIX III: CONTINUED

Run No.	Motor†	Speed rpm	Oil	Load	½	1	1½	2	3	4	6	8	10	12	13	14	15	16	19	24	30
22 §	F	1500	Z 5W-30		x		x	x	x	x	x	x	x	x		x		x			
23	F	3000	Y 5W-30		x		x	x	x	x	x	x	x	x		x	x				
24	F	1500	Y 5W-30		x		x	x	x	x	x	x	x	x		x		x			
25	H	3000	X 5W-30		x		x	x	x	x	x	x	x	x		x		x			
26	F	3000	Y 5W-30						x									x			
27	H	1500	X 5W-30		x		x	x	x	x	x	x	x	x		x		x			
28	F	3000	Y 5W-30	x	x		x	x	x	x	x	x	x	x		x		x			
29	H	3000	Y 5W-30		x		x	x	x	x	x	x	x	x		x		x			
30	H	1500	Y 5W-30		x		x	x	x	x	x	x	x	x		x		x			
31	H	3000	Z 5W-30		x		x	x	x	x	x	x	x	x		x		x			
32	H	1500	Z 5W-30		x		x	x	x	x	x	x	x	x		x		x			
33	H	3000	Y 10W-40		x		x	x	x	x	x	x	x	x		x		x			
34	H	1500	Y 10W-40		x		x	x	x	x	x	x	x	x		x		x			
35	H	3000	X 30		x		x	x	x	x	x	x	x	x		x		x			
36	H	1500	X 30		x		x	x	x	x	x	x	x	x		x		x			
37	H	3000	Z 10W-30		x		x	x	x	x	x	x	x	x		x		x			
38	H	3000	Y 10W-30		x		x	x	x	x	x	x	x	x		x		x			
39	H	3000	Y 5W-20		x		x	x	x	x	x	x	x	x		x		x			
40	H	3000	X 5W-20		x		x	x	x	x	x	x	x	x		x		x			
41	H	3000	X 5W-30		x		x	x	x	x	x	x	x	x		x		x			
42	H	3000	Z 5W-20		x		x	x	x	x	x	x	x	x		x		x			

† F refers to the 1949 Ford, H refers to the 292 Ford.

§ Prematurely terminated due to shortage of fuel.

\* Conducted with 80-87 fuel.



## APPENDIX IV: MOTOR TEMPERATURES AT THE ENDS OF RUNS.

Run No.	Speed rpm	Water (°F)		Oil (°F)	
		Thermometer	Thermocouple	Thermometer	Thermocouple
1	1500	151	-	158	-
2	1500	150	-	160	-
3	2250	152	-	166	-
4	3000	153	-	192	-
5	1500	150	-	160	-
6	2250	146	-	178	-
7	3000	152	-	175	-
8	2250	151	-	176	-
9	3000	151	-	195	-
10	2250	153	-	157	-
11	2250	154	-	181	-
12	1500	152	-	168	-
13	3000	152	-	202	-
14	1500	148	-	165	-
15	2250	152	-	182	-
16	1500	153	142	171	172
17	3000	151	147	204	210
18	3000	149	145	177	185
19	3000	150	145	180	198
20	3000	149	145	178	203
21	2250	152	145	164	179
22	1500	152	145	159	159
23	3000	-	144	-	198
24	1500	-	145	-	161
25	3000	-	167	-	209
*26	3000	151	-	188	-
27	1500	-	156	-	174
*28	3000	150	-	193	-
29	3000	-	170	-	205
30	1500	-	162	-	179
31	3000	-	172	-	217
32	1500	-	164	-	179
33	3000	-	172	-	220
34	1500	-	164	-	176
35	3000	-	171	-	224
36	1500	-	164	-	180
37	3000	-	172	-	220
38	3000	-	172	-	220
39	3000	-	173	-	218
40	3000	-	172	-	217
41	3000	-	173	-	219
42	3000	-	172	-	217

\* Only two thermocouples were available at any one time. Since both motors were running simultaneously, only one could be monitored.



## APPENDIX V: NEW OIL PROPERTIES

Oil <sup>§</sup>	API Gravity at 60°F	0 F Poise	100 F cs	210 F cs	Pour Point °F	Flash Point °F	VI <sub>e</sub>
Xa 5W-30	-	9.00	55.84	11.74	-25	420	224.46
X 10W-30	27.81	25.30	69.01	11.06	-30	385	163.29
X 5W-30	29.63	9.10	57.72	11.59	-35	375	212.99
Z 5W-30	28.03	10.00	57.33	11.60	-35	355	214.80
Y 5W-30	29.77	9.40	55.39	12.48	-20	395	244.12
Y 10W-40	28.83	19.00	97.39	16.43	-20	400	193.40
X 30	26.82	-*	123.28	12.07	-5	470	94.85†
Z 10W-30	28.43	23.30	69.70	11.89	-25	435	179.33
Y 10W-30	28.44	18.80	64.89	12.33	-25	415	203.60
Y 5W-20	29.58	8.80	42.13	9.21	-25	420	223.05
X 5W-20	29.48	6.50	36.93	7.43	-35	380	189.62
Z 5W-20	28.33	8.00	36.94	7.36	-40	375	182.58

\* Not measurable by C.C.S.

† VI not VI<sub>e</sub>

§ All were purchased at local service stations except Xa 5W-30, X 5W-30, and X 10W-30 which were obtained in bulk lots.



APPENDIX VI: USED OIL VISCOSITIES AND THEIR VISCOSITY INDICES.

Time Hrs.	Viscosities			VI <sub>e</sub>
	0 F Poise	100 F CS	210 F CS	
RUN NO. 1				
½	7.60	50.94	10.42	212.31
1	7.60	49.82	10.19	211.19
1½	7.60	49.56	10.03	207.78
2	7.60	48.33	10.02	213.61
3	7.60	47.91	9.90	210.89
4	7.60	47.39	9.70	208.85
6	7.60	46.01	9.52	210.58
8	7.61	45.44	9.33	207.66
10	7.60	44.58	9.21	208.45
12	7.60	44.12	9.10	207.43
14	7.50	43.75	9.00	206.04
16	7.60	43.46	8.99	207.36
RUN NO. 2				
½	8.00	50.82	10.41	212.61
1	7.80	49.83	10.27	213.40
1½	7.80	49.10	10.09	211.76
2	7.60	48.48	10.03	213.14
3	7.40	47.64	9.81	210.91
4	7.50	47.20	9.68	209.19
6	7.40	45.87	9.46	209.46
8	7.30	45.18	9.25	206.47
10	7.30	44.49	9.14	206.59
12	7.30	43.89	9.07	207.65
15	7.30	43.25	8.82	202.58
19	7.40	42.87	8.78	203.31
24	7.50	42.51	8.67	201.47
30	7.50	41.90	8.51	199.20
RUN NO. 3				
½	22.90	64.91	10.52	161.62
1	22.30	63.98	10.36	161.98
1½	22.30	63.10	10.28	162.79
2	22.00	62.36	10.16	162.67
3	21.90	61.87	10.08	160.98
4	21.80	61.13	9.93	159.68
6	21.80	60.59	9.82	158.58
8	21.80	60.07	9.68	156.57
10	22.00	60.25	9.68	155.99
12	22.10	59.85	9.61	155.47
16	22.60	59.95	9.58	154.35
RUN NO. 4				
½	23.2	64.90	10.48	161.73
1	23.00	63.97	10.32	161.20
1½	22.70	63.30	10.25	160.91
2	22.50	62.50	10.13	160.41
3	22.70	62.01	9.99	158.01
4	22.80	61.71	9.87	156.32
6	23.20	61.47	9.79	155.04
8	23.50	61.29	9.72	153.80
10	23.80	61.52	9.69	152.29
12	24.20	62.01	9.68	150.55
16	25.80	63.42	9.83	150.18





APPENDIX VI: CONTINUED

Time Hrs.	0 F Poise	Viscosities		VI <sub>e</sub>
		100 F CS	210 F CS	
RUN NO. 5				
½	19.20	59.34	9.91	165.00
1	20.50	60.37	9.98	163.41
1½	20.80	60.84	10.03	163.13
2	20.70	60.38	9.96	162.87
3	20.50	60.13	9.84	162.72
4	20.30	59.03	9.78	162.64
6	20.20	58.02	9.64	162.32
8	19.80	57.71	9.56	161.25
10	19.80	56.91	9.44	160.76
12	19.80	57.09	9.39	158.78
14	19.80	56.41	9.31	158.95
16	19.40	55.71	9.27	160.31
RUN NO. 7				
½	9.20	53.86	10.87	211.14
1	9.20	52.98	10.63	208.69
1½	9.20	52.33	10.48	207.58
2	9.20	51.93	10.38	206.60
3	9.30	51.45	10.19	203.50
4	9.40	51.10	10.09	202.20
6	9.80	50.86	10.02	201.34
8	10.10	51.35	9.98	198.00
10	10.30	51.93	10.02	196.51
12	10.70	52.97	10.09	193.92
13	10.80	53.45	10.15	193.59
RUN NO. 6				
½	9.40	54.42	10.99	211.73
1	9.20	53.29	10.72	209.67
1½	9.00	52.52	10.59	209.67
2	9.00	51.93	10.47	209.14
3	9.00	51.06	10.25	206.98
4	9.00	50.69	10.14	205.58
6	9.00	50.32	10.03	204.14
8	9.30	50.16	9.95	202.61
10	9.40	50.13	9.86	200.11
12	9.40	49.89	9.78	198.92
14	9.50	49.99	9.78	198.45
16	9.60	50.13	9.74	196.62
RUN NO. 8				
4	8.90	50.88	10.23	207.24
10	9.30	50.47	10.03	203.44
16	9.60	50.81	9.99	200.72
RUN NO. 9				
4	9.20	50.76	10.09	203.78
10	10.10	51.45	9.98	197.55
16	10.80	53.26	10.12	193.55



APPENDIX VI: CONTINUED

Viscosities					VI <sub>e</sub>
Time Hrs.	0 F Poise	100 F cs	210 F cs		
RUN NO. 11					
½	8.40	53.07	10.82	213.29	
1	8.30	51.78	10.62	213.86	
2	8.20	50.38	10.33	212.44	
3	8.10	49.74	10.17	210.99	
4	8.00	49.17	10.04	209.95	
6	8.30	48.87	9.88	206.76	
8	8.40	48.83	9.78	204.02	
10	8.50	48.57	9.73	203.79	
12	8.70	48.73	9.69	201.77	
14	8.80	48.82	9.66	200.42	
16	9.00	49.08	9.69	200.07	
RUN NO. 13					
½	8.60	52.37	10.72	213.82	
1	8.60	51.50	10.50	211.92	
2	8.70	50.47	10.16	207.20	
4	8.90	49.61	9.95	205.23	
6	9.30	49.94	9.89	201.88	
8	9.60	50.19	9.86	199.83	
10	10.00	50.91	9.87	196.80	
12	10.50	51.82	9.97	195.62	
14	11.00	53.49	10.17	193.98	

Viscosities					VI <sub>e</sub>
Time Hrs.	0 F Poise	100 F cs	210 F cs		
RUN NO. 10					
½	8.30	53.59	10.94	214.10	
1	8.00	52.28	10.72	214.23	
1½	7.80	51.25	10.54	214.18	
2	7.80	50.42	10.42	214.80	
3	7.70	49.40	10.18	212.97	
4	7.60	48.55	10.06	213.63	
6	7.60	47.65	9.84	211.74	
8	7.60	46.89	9.66	210.19	
10	7.70	46.67	9.56	208.30	
12	7.80	46.41	9.49	207.50	
14	7.80	46.10	9.43	207.28	
16	7.80	45.73	9.32	205.79	
RUN NO. 12					
½	8.10	52.75	10.85	215.56	
1	7.90	51.73	10.65	214.90	
2	7.60	50.23	10.40	215.16	
3	7.60	49.41	10.22	214.05	
4	7.60	48.72	10.11	214.27	
6	7.50	48.10	9.92	211.84	
8	7.60	47.58	9.83	211.80	
10	7.70	47.50	9.77	210.42	
12	7.70	47.11	9.65	208.75	
14	7.70	46.68	9.56	208.25	
16	7.70	46.67	9.50	206.45	



APPENDIX VI: CONTINUED

Viscosities					
Time Hrs	0 F Poise	100 F cs	210 F cs	VI <sub>e</sub>	
RUN NO. 14					
4	7.70	48.33	10.01	213.32	
10	7.60	46.65	9.55	208.09	
16	7.80	45.23	9.25	206.20	
RUN NO. 16					
4	7.60	48.67	10.11	214.52	
10	7.60	46.94	9.70	211.20	
16	8.1	47.02	9.66	209.51	
RUN NO. 18					
1/2	§	54.30	10.86	208.96	
1		53.29	10.68	208.61	
2		52.47	10.44	205.85	
4		52.23	10.21	200.54	
6		51.92	10.14	199.96	
8		52.32	10.11	197.31	
10		52.88	10.13	195.45	
12		53.30	10.14	193.95	
16		55.09	10.30	190.90	
RUN NO. 15					
4	8.30	49.55	10.10	209.85	
10	8.50	48.53	9.79	205.80	
16	9.00	48.86	9.70	201.46	
RUN NO. 17					
4	9.20	49.89	9.98	204.78	
10	10.10	50.52	9.88	198.88	
16	11.20	52.37	10.00	194.02	
RUN NO. 19					
1/2	8.90	53.90	10.87	210.97	
2	9.20	52.42	10.43	205.79	
4	9.30	51.83	10.25	203.44	
6	9.60	51.82	10.16	200.98	
8	9.90	52.03	10.12	198.89	
10	10.20	52.47	10.13	197.23	
12	10.60	52.93	10.12	194.96	
16	11.30	54.20	10.18	191.12	

§ No values were measured.



APPENDIX VI: CONTINUED

Viscosities				
Time Hrs.	0 F Poise	100 F cs	210 F cs	VI <sub>e</sub>
RUN NO. 21				
$\frac{1}{2}$	9.50	54.50	11.07	213.45
2	9.60	53.49	10.74	209.29
4	10.20	53.68	10.63	205.61
6	10.60	54.09	10.61	203.32
8	10.90	54.70	10.64	201.52
10	11.20	55.58	10.69	199.19
12	11.70	56.46	10.75	197.15
14	12.00	57.29	10.82	195.70
16	12.30	58.11	10.81	192.34
RUN NO. 23				
$\frac{1}{2}$	9.40	50.03	10.85	228.62
2	9.50	46.51	9.90	219.62
4	9.60	45.42	9.52	213.82
6	9.60	45.08	9.30	208.67
8	9.80	44.76	9.20	207.11
10	9.80	44.71	9.12	204.70
12	9.80	44.74	9.05	202.18
14	10.00	44.76	8.99	200.04
15 $\frac{1}{4}$	10.10	44.98	9.01	199.54

Viscosities				
Time Hrs.	0 F Poise	100 F cs	210 F cs	VI <sub>e</sub>
RUN NO. 20				
$\frac{1}{2}$	9.70	53.76	10.92	212.84
2	10.20	52.86	10.55	207.09
4	10.60	52.93	10.41	202.97
6	11.10	53.93	10.42	198.93
8	11.90	55.09	10.56	197.82
10	12.80	56.51	10.59	192.91
12	13.30	57.92	10.73	191.03
16	14.80	60.68	10.99	187.39
RUN NO. 22				
$\frac{1}{2}$	9.10	53.73	11.05	216.32
2	8.60	51.21	10.58	215.47
4	8.50	50.23	10.34	213.44
6	8.60	49.89	10.22	211.69
8	8.60	49.68	10.15	210.69
10	8.60	49.61	10.08	208.94
12	8.70	49.50	9.99	206.92
14	8.70	49.31	9.96	207.00
16	8.70	49.25	9.92	206.10





## APPENDIX VI: CONTINUED

Viscosities					
Time	0 F	100 F	210 F	VI <sub>e</sub>	
Hrs.	Poise	cs	cs		
RUN NO. 24					
1/2	9.00	50.26	11.40	242.24	
2	8.40	46.68	10.42	234.32	
4	8.10	44.53	9.93	231.88	
6	7.90	43.38	9.52	225.70	
8	7.80	42.48	9.28	223.32	
10	7.70	41.57	9.16	224.84	
12	7.60	41.65	9.02	219.41	
14	7.60	41.13	8.92	219.17	
16	7.40	40.63	8.80	217.93	
RUN NO. 25					
1/2	8.60	53.21	10.73	210.28	
2	8.70	49.07	9.92	206.98	
4	8.80	47.40	9.33	197.39	
6	9.00	46.57	9.14	195.45	
8	9.20	46.47	9.03	192.37	
10	9.40	46.60	8.97	189.73	
12	9.60	46.78	8.96	188.52	
14	9.80	47.06	8.94	186.45	
16	9.90	47.17	8.92	185.26	
RUN NO. 26					
4	9.20	44.57	9.37	213.82	
10	9.30	43.41	8.89	204.18	
16	9.60	43.33	8.73	198.87	
RUN NO. 27					
1/2	8.50	53.83	10.97	213.80	
2	8.10	50.79	10.35	211.03	
4	7.80	48.82	9.95	209.10	
6	7.80	47.65	9.66	206.25	
8	7.90	47.13	9.54	205.26	
10	8.10	46.61	9.37	202.70	
12	8.10	46.44	9.28	200.73	
14	8.20	46.33	9.25	200.32	
16	8.30	45.96	9.13	198.27	



## APPENDIX VI: CONTINUED

Viscosities				
Time	0 F	100 F	210 F	VI <sub>e</sub>
Hrs.	Poise	cs	cs	
RUN NO. 28				
1/2	9.20	48.91	10.75	231.57
2	8.70	45.36	9.82	223.61
4	8.60	43.65	9.30	216.86
8	8.70	42.56	8.91	209.88
10	9.00	42.53	8.90	209.73
12	9.10	42.21	8.73	205.42
14	9.00	41.90	8.63	203.65
16	9.00	41.55	8.61	205.04
RUN NO. 29				
1/2	9.70	50.59	11.09	232.23
2	9.40	45.90	9.65	215.24
4	9.40	43.78	9.05	207.58
6	9.40	42.96	8.72	200.65
8	9.40	42.39	8.56	198.17
10	9.50	41.85	8.37	194.06
12	9.50	41.40	8.24	191.72
14	9.60	40.94	8.04	186.36
16	9.60	40.69	8.00	186.22
RUN NO. 30				
1/2	9.40	50.90	11.39	238.70
2	8.90	47.65	10.45	229.86
4	8.80	45.50	9.83	223.09
6	8.60	44.03	9.42	218.56
8	8.40	42.99	9.14	215.31
10	8.40	42.44	8.96	212.40
12	8.40	41.89	8.79	209.56
14	8.40	41.66	8.71	208.04
16	8.40	41.37	8.63	206.89
RUN NO. 31				
1/2	9.40	52.42	10.72	213.59
2	9.50	50.30	10.03	204.23
4	10.00	49.80	9.68	196.35
6	10.70	50.05	9.62	193.42
8	11.20	50.72	9.57	188.93
10	11.80	51.38	9.58	186.29
12	12.30	52.05	9.59	183.71
14	12.80	52.68	9.63	182.20
16	13.40	53.88	9.73	180.16



# APPENDIX VI: CONTINUED

Viscosities					VI <sub>e</sub>
Time Hrs.	0 F Poise	100 F cs	210 F cs		
RUN NO. 32					
1½	8.90	52.01	10.85		218.98
2	8.80	50.05	10.30		213.19
4	9.00	48.87	9.98		209.75
6	9.00	48.38	9.74		205.04
8	9.10	48.08	9.64		203.49
10	9.20	48.00	9.52		200.25
12	9.60	47.98	9.49		199.44
14	9.80	47.92	9.43		197.91
16	10.00	48.05	9.42		196.95
RUN NO. 34					
1½	16.70	90.40	15.47		193.17
2	15.90	85.04	14.81		194.49
4	15.40	81.70	14.13		191.01
6	15.30	79.63	13.79		190.10
8	15.20	78.18	13.53		189.00
10	15.10	77.01	13.36		188.83
12	15.00	75.94	13.13		187.22
14	15.00	75.41	13.04		186.88
16	15.10	74.55	12.90		186.47

\* Not measurable by C.C.S.

† VI not VI<sub>e</sub>

Viscosities					VI <sub>e</sub>
Time	0 F	100 F	210 F	cs	
Hrs.	Poise	cs	cs		
RUN NO. 33					
1½	17.60	88.84	15.13		191.20
2	17.00	81.62	13.94		187.91
4	16.80	77.81	13.21		183.99
6	16.90	75.63	12.85		182.68
8	17.20	74.18	12.54		180.44
10	17.30	73.31	12.38		179.52
12	17.40	72.45	12.22		178.61
14	17.40	71.92	12.11		177.76
16	17.50	71.39	11.99		176.67
RUN NO. 35					
1½	*	116.31	11.69		96.06†
2		113.88	11.56		96.58
4		113.67	11.51		96.05
6		113.43	11.56		97.04
8		113.84	11.56		96.62
10		114.18	11.61		97.00
12		114.52	11.63		97.13
14		114.92	11.67		97.24
16		115.11	11.69		97.24



# APPENDIX VI: CONTINUED

Viscosities					
Time Hrs.	0 F Poise	100 F cs	210 F cs	VI <sub>e</sub>	
RUN NO. 36					
1/2	*	116.03	11.65	95.74†	
2		111.78	11.44	96.95	
4		110.32	11.29	96.21	
6		109.55	11.27	96.72	
8		108.92	11.25	97.08	
10		108.79	11.23	96.91	
12		108.51	11.20	96.93	
14		108.50	11.23	97.22	
16		108.25	11.23	97.49	
RUN NO. 37					
1/2		22.50	65.63	10.89	169.13
2		22.00	62.26	10.14	161.42
4		22.00	61.08	9.72	154.45
6		22.40	60.66	9.59	152.37
8		22.60	60.42	9.48	150.26
10		23.00	60.50	9.44	148.96
12		23.20	60.66	9.40	147.43
14		23.30	60.69	9.38	146.80
16		23.50	60.98	9.36	145.40
RUN NO. 38					
1/2		18.50	58.22	10.76	190.65
2		17.80	54.18	9.67	177.24
4		17.60	52.28	9.19	171.02
6		17.70	51.63	8.96	166.69
8		17.70	51.18	8.82	164.10
10		17.90	50.99	8.73	161.98
12		18.00	50.91	8.67	160.40
14		18.20	50.90	8.63	159.17
16		18.30	51.06	8.62	158.22
RUN NO. 39					
1/2		8.60	39.09	8.28	207.91
2		8.60	36.49	7.54	193.89
4		8.70	35.60	7.20	184.56
6		8.80	35.12	7.05	180.81
8		8.80	35.01	6.97	177.68
10		8.80	34.92	6.90	174.63
12		8.80	34.87	6.88	173.90
14		9.00	34.92	6.86	172.50
16		9.10	35.01	6.84	170.83

\* Not measurable by C.C.S.

† VI not VI<sub>e</sub>





APPENDIX VI: CONTINUED

Viscosities				
Time	0 F	100 F	210 F	VI <sub>e</sub>
Hrs.	Poise	cs	cs	
RUN NO. 40				
1½	6.40	34.75	7.13	187.44
2	6.20	33.37	6.85	183.45
4	6.40	33.04	6.68	176.79
6	6.50	33.01	6.65	175.44
8	6.70	33.07	6.63	173.91
10	6.80	33.43	6.66	172.76
12	6.80	33.78	6.67	170.72
14	7.00	34.07	6.70	170.20
16	7.20	34.38	6.71	168.47

RUN NO. 42				
1/2	7.90	35.35	7.11	182.06
2	7.80	35.06	6.88	172.56
4	8.60	35.52	6.84	167.32
6	9.20	36.10	6.87	164.99
8	9.60	36.95	6.92	162.11
10	10.10	37.58	6.97	160.68
12	10.50	38.40	7.04	158.99
14	10.90	39.17	7.10	157.20
16	11.30	39.89	7.18	156.63

Viscosities				
Time Hrs.	0 F Poise	100 F cs	210 F cs	VI <sub>e</sub>
RUN NO. 41				
1½	8.50	53.35	10.86	213.13
2	8.40	50.04	10.11	207.77
4	8.60	48.66	9.77	204.55
6	8.80	48.29	9.54	199.41
8	9.00	48.12	9.50	199.06
10	9.20	48.24	9.44	196.62
12	9.50	48.54	9.42	194.56
14	9.80	48.82	9.40	192.62
16	10.00	49.07	9.40	191.44



APPENDIX VII: FUEL DILUTION, INSOLUBLES, AND OXIDATION PRODUCTS  
FOR END SAMPLES.

Run No.	% Dilution	Fuel Oxidation Products %	% Insolubles	Run No.	% Dilution	Fuel Oxidation Products %	% Insolubles
1	-	0.24	0.51	22	1.80	0.11	0.41
2	1.40	0.14	1.00	23		0.28	0.72
3				24	1.50	0.10	0.41
4		0.42	0.68	25	1.20	0.47	0.56
5		0.17	0.49	26		0.11	0.67
6	1.20	0.40	0.50	27	1.00	0.19	0.37
7	0.60	0.13	0.81	28	1.00	0.25	1.34
8	1.00	0.38	0.85	29	0.40	0.28	0.41
9	0.80			30		0.20	0.50
10	2.40	0.28	0.45	31	1.20	0.10	0.45
11	1.20			32	1.40	0.14	0.37
12	1.80	0.20	0.95	33	0.40	0.14	0.50
13	0.50	0.21	1.81	34			
14	2.00	0.12	0.49	35	0.48	0.22	0.66
15	1.60	0.41	1.47	36	0.60	0.16	0.24
16	1.50	0.32	0.63	37		0.12	0.38
17	1.20	0.43	1.67	38	0.80		
18				39	0.80	0.16	0.70
19	0.12	0.27	0.69	40	0.60		
20		0.12	0.51	41		0.13	0.85
21	0.40	0.16	0.68	42	0.48	0.14	0.54



APPENDIX VIII: UNIVERSITY VEHICLES: VISCOSITIES AND PERCENTAGE  
CRANKCASE DILUTION.

Mileage on motor at start of test	Mileage on oil	Per cent dilution	Viscosities	
			0 F poise	210 F cs
23206	14	0.80	20.6	9.90
14671	288	1.28	19.8	9.69
30743	481	0.60	16.5	8.99
39078	575	1.00	16.8	8.68
22319	669	1.60	16.7	8.40
10989	854	1.20	20.5	8.31
13033	873	0.80	25.6	9.25
3859	929	0.80	17.5	8.64
53863	1004	1.80	21.6	8.77
64049	1033	1.88	19.0	8.89
26071	1110	1.00	23.3	9.95
22401	1198	1.60	20.7	10.81
28219	1279	1.20	21.2	10.01
10775	1375	1.48	20.3	9.24
26191	1414	1.00	21.3	9.60
26565	1729	1.40	21.3	9.65
43894	1749	0.88	21.9	8.93
22000	1897	0.20	27.0	10.28
5552	2442	1.60	21.2	9.36
44527	2514	1.88	32.0	9.61
3514	2703	1.40	37.0	10.68
36263	2782	1.60	26.6	9.83
38215	3221	1.80	41.0	12.37
47071	3711	1.40	25.3	9.52
2126	4393	0.32	33.0	9.75
New Oil	-	-	25.3	11.06



## APPENDIX IX: EFFECTS OF DILUTION ON VISCOSITY.

% Gasoline Added	0 F Poise	% of Original	Viscosities		210 F cs	% of Original
			100 F cs	% of Original		
0.0	9.10	100.00	57.72	100.00	11.59	100.00
1.0	8.35	91.76	55.39	95.66	11.33	97.76
2.0	7.80	85.71	53.70	93.04	11.16	96.29
2.5	6.83	66.29	48.43	83.91	10.52	90.76
3.0	5.80	63.74	47.41	82.14	10.41	89.82





## APPENDIX X: VOLATILITY TESTS.

Oil	Time from start in hours	% Weight loss	0 F poise	Percent of Original	100 F cs	Percent of Original	210 F cs	Percent of Original
X 5W-30	0	-	9.10	-	57.72	-	11.59	-
	1	0.102	9.10	100.00	57.34	99.35	11.59	100.00
	2	0.178	9.10	100.00	57.49	99.60	11.63	100.35
	4	0.266	9.15	100.56	57.69	99.95	11.70	100.95
	8	0.470	9.25	101.67	58.04	100.56	11.73	101.21
Z 5W-30	0	-	10.00	-	57.33	-	11.60	-
	1	0.118	10.15	101.50	57.02	99.46	11.62	100.17
	2	0.220	10.21	102.10	57.04	99.49	11.63	100.26
	4	0.444	10.42	104.20	57.35	100.04	11.68	100.69
	6	0.598	10.63	106.30	57.79	100.81	11.71	101.03
	19	1.627	11.25	112.50	59.63	104.01	11.97	103.26
Y 5W-30	0	-	9.40	-	55.39	-	12.48	-
	1	0.064	9.40	100.00	55.43	100.07	12.45	99.76
	2	0.078	9.40	100.00	55.41	100.04	12.48	100.00
	4	0.108	9.40	100.00	55.65	100.47	12.45	99.76
	8	0.158	9.43	100.29	55.85	100.84	12.45	99.76
	16.5	0.288	9.49	100.98	56.00	101.11	12.47	99.92









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